

Sortie Generation Capacity of Embarked Airwings

Angelyn Jewell

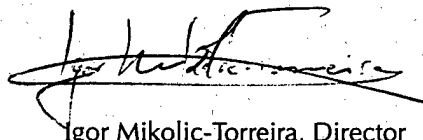
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13. ABSTRACT (Maximum 200 words) The Naval Strike and Air Warfare Center (NSAWC) asked the Center for Naval Analyses to help evaluate and analyze carrier and air wing sortie-generation capacity. Specifically, we set out to determine the firepower capacity of an embarked air wing, the factors that constrain the sortie-generation capacity, and ways to enhance the fire power capacity. In this paper, we create a base case focusing on the three major requirements of the creation of sea-based air power: the aircraft must be mission capable, the aircrew must ready aircraft for flight, launch aircraft, and recover aircraft after the airframes, the aircrew, and the carrier and air wing's ability to launch, recover, and ready aircraft for launch rely on the characteristics of the base case.					
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Contents

Summary	1
Introduction	1
CV/CVW firepower capacity calculation guide	3
Examples of use	5
What limits firepower capacity?	14
What can be done to increase firepower capacity?	17
Base case	27
Conditions pertaining to airframe capacity	30
Conditions pertaining to aircrew capacity	31
Conditions pertaining to flight deck operations	33
Airframe capacity	35
Capacity of airframes in the base case	36
Adapting airframe capacity estimates to other air plans	42
When might the airframe capacity be less?	43
Fewer MC airframes available	43
Deck-edge elevators not used during flight operations	44
Shorter operating day	44
Non-uniform operating tempo	44
Accidents or combat damage occur	44
Flight operations interrupted or degraded due to conduct of preventative maintenance and servicing	45
Insufficient tanker support	46
Insufficient electronic warfare support	49
Extended duration of operations	50
How can airframe capacity be increased?	50
Conduct flight operations 24 hours a day	54
Permit sortie-completion rates as low as 85 percent	54
Pool F/A-18 resources	55
Super spare strike/fighters	56

Preemptively request spare parts and servicing expendables in anticipation of need	57
Increase O-level aviation maintenance manning	59
Aircraft augmentation	61
Pilot and aircrew capacity	65
Capacity of pilots in the base case	66
Setting the cap on pilot utilization rate	66
U.S. Navy and U.S. Air Force doctrine	67
Mission overhead—preparation and debrief.	70
When might pilot capacity be less?	73
Fewer pilots available	73
Administrative tasks cannot be postponed	74
Pilot utilization rates below cap	74
Fatigue and combat stress reduce pilot utilization rate	74
How can pilot capacity be increased?	75
Reduce the non-flying tasking of air wing pilots	75
Reduce the time pilots spend in mission planning, preparation, and debriefing	75
Pool F/A-18 pilots.	78
Reduce fatigue of pilots	79
Augmentation—pilots and support personnel	79
Determining augmentation size: example	80
Tap other onboard, qualified aviators	81
Reduce the number of spares manned	82
Reduce the amount of crew rest	82
Flight deck capacity	83
Capacity of the flight deck in the base case	84
Aircraft turnaround.	88
Time available	88
Respot, fueling, and servicing processes	88
Ordnance process	91
Launch and recovery operations.	93
Other factors affecting flight deck capacity	95
When might the flight deck capacity be less?	96
Flight operations conducted 24 hours a day.	96
Permit sortie-completion rates as low as 85 percent	97

Strike/fighters configured with more ordnance or their ejection racks must be changed frequently . .	97
Gun loading	98
Failure of weapon hoists	98
Cycle times less than 1+15	98
Flight deck density	99
Manning not at billets authorized	99
Need to replenish	100
Deck-edge elevators not available to transfer ordnance and skids	100
Hazards of electromagnetic radiation to ordnance conditions	101
How can the flight deck capacity be increased?	101
Pool F/A-18 resources	101
ORM considerations	101
Augment air wing ordnance crews and carrier air, weapons, and operations departments	103
References	105
List of figures	109
List of tables	111

Summary

Introduction

Sortie generation is a key component of the U.S. Navy's ability to project power against an enemy. Consequently, sortie generation is a fundamental measure of carrier and air wing capability and is used extensively throughout the U.S. Navy and the Department of Defense (DOD). For example, estimates of sortie-generation potential are used by the commanders-in-chief to develop operational plans and by the Chief of Naval Operations (CNO) in budget discussions with the Secretary of Defense.

The Naval Strike and Air Warfare Center (NSAWC) asked the Center for Naval Analyses (CNA) to help evaluate and analyze carrier and air wing sortie-generation capacity. Specifically, we set out to determine the firepower capacity of an embarked air wing, the factors that constrain the sortie-generation capacity, and ways to enhance the firepower capacity. Amplifying information on the analyses presented here can be found in the appendix [1], which is published separately.

The creation of sea-based air power is a complex process, involving hundreds of people and sophisticated machines. Aircraft are launched, recovered, dearmed, spotted, repaired, exchanged with hangar deck aircraft, serviced, fueled, configured with ordnance, and armed all within the few minutes of a deck cycle. In this paper, we focused on the three major requirements of this process:

- *Aircraft* must be mission capable (MC).
- *Aircrew* must be available to fly the aircraft.
- *Flight deck* crews must ready aircraft for flight, launch aircraft, and recover the aircraft after completion of their missions.

The carrier and air wing meet these requirements with the assets they have available—personnel and equipment—within the context of their assigned mission and the operating environment.

We first studied each requirement separately and then combined them to determine which requirement was the most difficult to meet under specific operational conditions.

We based our estimates of firepower capacity on fleet data. Information on airframe reliability and launch and recovery operations is abundant. We accessed the U.S. Navy's Subsystem Capability Impact Reporting (SCIR) database to determine the rates at which embarked aircraft break and their subsequent repair times. These data are fundamental to our estimate of airframe capacity. We used data from recent high-intensity flight operations on *Nimitz*-class carriers to determine the time required to launch and recover aircraft. Quantitative data relating to the aircrew and flight deck requirements for firepower generation are scarcer. In these cases, we supplemented the available quantitative data with qualitative inputs from fleet operators.

Estimating aircrew capacity is less straightforward than considering airframe reliability. At the heart of this analysis lies the question, "What is the maximum number of combat sorties per day an aircrew can be expected to execute?" Many factors must be considered when answering this question—such as the complexity of the mission and non-combat tasking of the aircrew. We focused on the influence of the time available to the aircrew to perform the necessary tasks. Although the amount of time spent planning and preparing for a combat sortie and in post-mission debrief can vary considerably, we used estimates provided by NSAWC to estimate the typical time required to complete these specific tasks.

The capacity of the flight deck crews to ready aircraft is by far the most difficult of the major requirements to estimate. Flight operations are the product of the efforts of many people, some working in concert with each other and others working in isolation. Some tasks can be performed simultaneously; some must wait the completion of others. To estimate the capacity of the flight deck to ready aircraft, we used fleet data to determine the relative order in which these tasks are

conducted, the typical time required to perform them, and the number of personnel available to conduct these tasks.

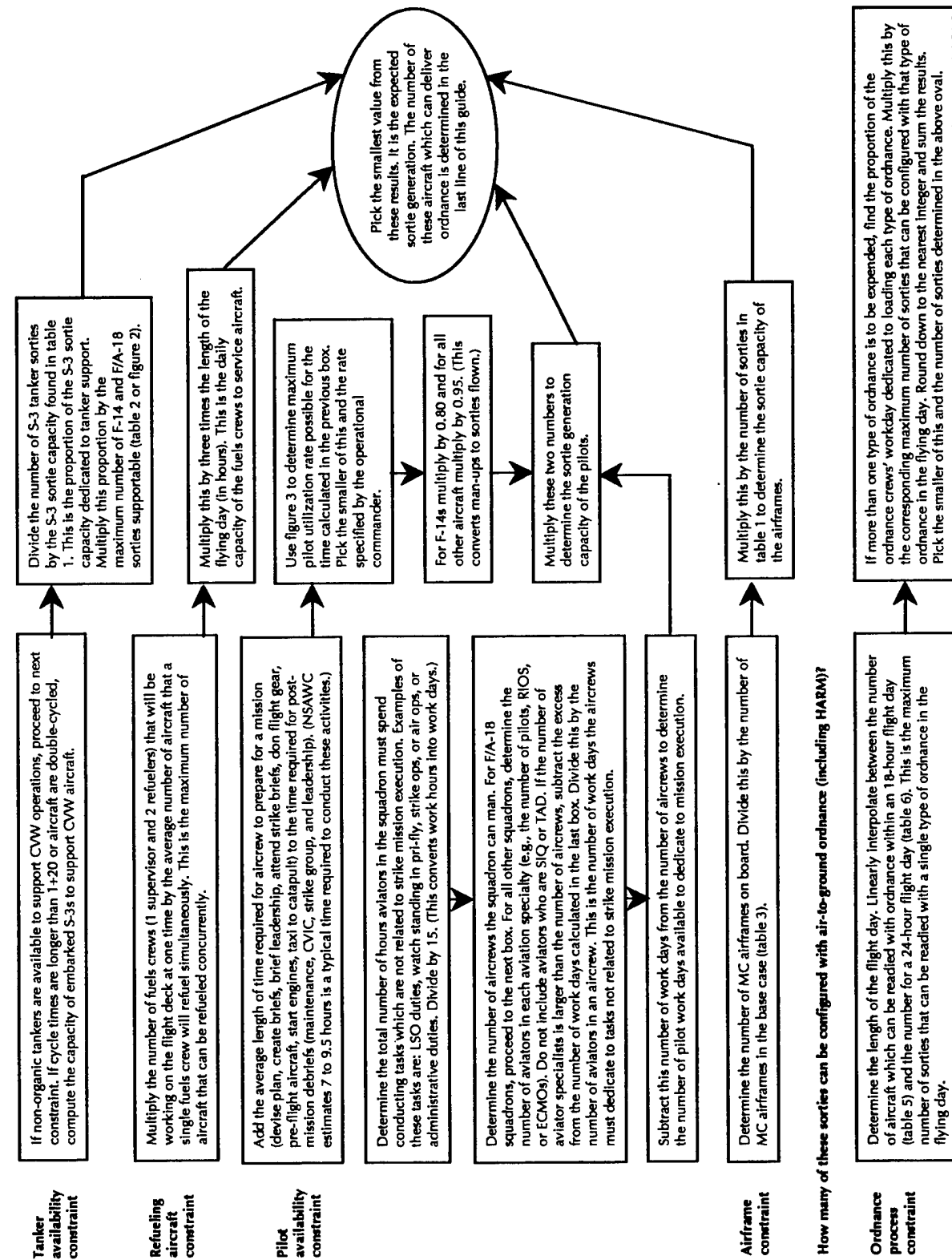
We based our estimates of the capacity of the carrier and air wing to complete each of the major requirements on "operations as normal," as typified by a base case. We modeled our base case on operational employment typical of current deployed carrier battle groups with standard resources and support available. Our base case has a *Nimitz*-class carrier with 46 embarked strike/fighters¹ conducting flight operations for 18 hours in each 24-hour day. We used the readiness goals set by the CNO for mission-capable (MC) rates for the air wing at the beginning of high-intensity flight operations [2]. We used manning levels typical of current deployments. Because the tasking to a carrier battle group can vary significantly from one operational situation to the next, we estimated the sortie-generation capacity under a variety of cycle times and multiples.

CV/CVW firepower capacity calculation guide

Different circumstances can radically alter which operational factor limits sortie generation. We present in figure 1 a guide to estimating the firepower capacity of a carrier and air wing. To use this guide, the cycle time, cycle multiple, and the length of the flying day are required inputs. This research memorandum details the assumptions behind and derivation of the information found in the tables and figures referenced in figure 1.

-
1. The CNO has directed that the number of aircraft in each F-14 squadron be cut to ten. Our projections of the firepower capacity of the air wing uses this new air wing composition. The reader must use caution when comparing our estimates of the sortie-generation capacity of the F-14 squadrons to past fleet experiences for which 14 F-14s were on board.

Figure 1. CV/CVV firepower capacity guide



Examples of use

The following examples are provided to illustrate the use of the sortie generation calculation guide (figure 1). As we walk through the examples, we encourage you to use figure 1 to follow the logic in the CV/CVW firepower capacity guide. The examples are chosen to roughly coincide with that of the base case (described in the next section). We include here the key tables and figures used to calculate the estimate of sortie generation in the two examples. These figures and tables are repeated later in the text of this memorandum, where their deviation and use are explained in detail. Table 1 shows estimated sortie generation capacity under a variety of ways in which onboard resources may be used. For these examples, use the estimates for the base case (shown in the first column of table 1).

Example 1: Operational conditions. Suppose the operating day was 18 hours long and 1+30 single-cycles were employed. Non-organic tankers are not available to support air wing operations. Twelve S-3 sorties (one each cycle) can be dedicated to tanker missions in support of strike operations. A minimum of two fuels crews will be working the flight deck concurrently. Each fuels crew can refuel two aircraft simultaneously. The operational commander has set a cap on the pilot utilization rate of 3.0. Each F/A-18 squadron has 17 pilots. The F-14D squadron has 17 pilots and 17 Radar Intercept Officers (RIOs). One F-14 pilot is TAD and two F/A-18 pilots are SIQ. Each squadron requires about 40 hours each day from their aviator work force for duties not directly related to execution of a specific mission. On average, 6 hours are required to prepare (plan, brief, and pre-flight the aircraft) each strike mission, and post-mission debriefs take about 1.5 hours. Eight of the 10 F-14Ds and 30 of the 36 F/A-18s on board are MC for strike warfare at the beginning of the operation. Air plans are designed to achieve at least a 95 percent sortie completion rate. (Note: these operating conditions concur with those of the base case used in this memorandum and described in detail in the next section.)

Tanker availability constraint. Because non-organic tankers are not available and the 1+30 cycle time is longer than 1+20, air wing sortie generation may be limited by the number of S-3 tankers. The S-3s can

generate up to 22 tanker sorties (table 1). The proportion of S-3 sortie capacity dedicated to tanker support is $0.55 (= 12 / 22)$. Table 2 indicates that the F-14s do not require tanking and, if all the S-3s are dedicated to tanking missions, up to 240 F/A-18 sorties can be supported. (For missions requiring a longer flight time, the number of F/A-18 and F-14 sorties which can be supported can be found in figure 2.) Multiplying the proportion of S-3 sortie capacity dedicated to tanker support by the number of F/A-18 sorties which are supportable gives 132 ($= 0.55 \times 240$) F/A-18 sorties.

Refueling aircraft constraint. The maximum number of aircraft that can be refuelled simultaneously is 4 ($= 2 \times 2$). The capacity of the fuels crews is 213 ($= 4 \times 3 \times 18$).

Pilot availability constraint. Pre-mission and post-mission activities require on average 7.5 ($= 6 + 1.5$) hours to complete. Enter this combined preparation and debrief time (7.5 hours) on the vertical axis of figure 3. Interpolating between the curves for cycle times of 1+15 and 1+45 gives a maximum pilot utilization rate of 1.4. This is smaller than the cap (3.0) the operational commander placed on pilot utilization rate. The maximum number of sorties each F-14 pilot can be expected to complete is 1.1 ($= 1.4 \times 0.80$) and for F/A-18 pilots is 1.3 ($= 1.4 \times 0.95$)

Grouping the pilots from the three F/A-18 squadrons together gives 49 ($= (3 \times 17) - 2$) F/A-18 pilots are available to fly. The number of work days the F/A-18 pilots spend in non-mission tasks is 8 ($= 40 \times 3 / 15$). The number of F/A-18 pilot work days available to dedicate to mission execution is 41 ($= 49 - 8$).

Sixteen ($= 17 - 1$) F-14 pilots and 17 F-14 RIOs are available to fly. This means the F-14 squadron has enough aviators to man 16 F-14 aircrews, with one additional F-14 RIO. The number of work days F-14 aviators spend in non-flying tasks is 2.7 ($= 40 / 15$). Because there is one additional RIO, the number of work days the 16 F-14 aircrews must spend in non-mission duties is 1.7 ($= 2.7 - 1$). Because there are two aviators in an F-14 aircrew, the number of F-14 pilot work days available to dedicate to mission execution is 15.2 ($= 16 - (1.7 / 2)$).

The sortie-generation capacity of the F-14 pilots is 17 ($= 1.1 \times 15.2$) and for the F/A-18 pilots is 53 ($= 1.3 \times 41$).

Airframe constraint: Dividing the number of MC F-14s and F/A-18s by the number needed to meet the CNO goals (table 3) gives 1.14 ($= 8 / 7$) for the F-14s and 1.11 ($= 30 / 27$) for the F/A-18s. Multiplying by the corresponding values in table 1 gives 29 ($= 1.14 \times 25$) F-14 sorties and 130 ($= 1.11 \times 39 \times 3$) F/A-18 sorties.

Sortie generation possible—overlay of constraints: The sortie-generation constraints we calculated are summarized in table 4.

Ordnance process constraint: From table 5, the maximum number of F-14s that can be loaded with ordnance varies between 9 and 19 and for the F/A-18s the number varies between 51 ($= 17 \times 3$) and 114 ($= 38 \times 3$).

Example 2: Operating conditions. Suppose in the last example the carrier and air wing are required to launch on each cycle at least one F-14 configured with 2 Mk 83 GP bombs, for delivery on enemy targets. What is the firepower capacity of the F-14 squadron under these constraints?

Tanker availability constraint. Same as example 1.

Refueling aircraft constraint. Same as example 1.

Pilot availability constraint. Same as example 1.

Sortie generation possible—overlay of constraints: Same as example 1. At most 17 F-14 sorties can be generated.

Ordnance process constraint: Because there are 12 cycles in the 18-hour flying day, the carrier and air wing are required to generate at least 12 F-14 sorties, each configured with 2 Mk 83 GP bombs. From table 5, at most 19 F-14s that can be readied with 2 Mk 83 GP bombs. The proportion of the F-14 ordnance crews' workday dedicated to loading the twelve required F-14 sorties is 0.63 ($= 12 / 19$). The remainder of their workday, 0.37 ($= 1 - 0.63$) of a day, can be spent loading other F-14s. This time can be spent loading 7 ($= 0.37 \times 19$) additional F-14s with Mk 82/83 GP, 4 ($= 0.37 \times 13$, after rounding down to the nearest

integer) additional F-14s with Mk 84 GP, Rockeye, or Gator, or 3 ($= 0.37 \times 9$, after rounding down to the nearest integer) additional F-14s loaded with LGBs. Because the sortie generation of the F-14s is limited to 17, the number of F-14 sorties delivering air-to-ground ordnance on enemy targets is: 17 (all F-14s loaded with 2 Mk 82/83 GP bombs), 16 (12 F-14s loaded with 2 Mk 83 GP and 4 F-14s loaded with 2 Mk 84 GP, 2 Rockeye, or 2 Gator), or 15 (12 F-14s loaded with 2 Mk 83 GP and 3 F-14s loaded with 2 LGBs).

Table 1. Potential gains in the capacity of airframes (each squadron)

	Base case and flight quarters 24 hours a day	... and SCR of 85 percent	... and pool F/A-18 squadrons	... and augment maintenance / aggressive logistics policy
F-14:					
1+15, single-cycle	27	32	39	n/a	46
1+20, single-cycle	26	32	38	n/a	45
1+30, single-cycle	25	31	36	n/a	43
1+45, single-cycle	23	29	33	n/a	39
1+15, double-cycle	21	27	32	n/a	36
1+20, double-cycle	20	25	31	n/a	34
1+30, double-cycle	19	25	29	n/a	31
1+45, double-cycle	17	23	26	n/a	29
F/A-18C ^a :					
1+15, single-cycle	43	56	64	72	80
1+20, single-cycle	42	54	62	70	77
1+30, single-cycle	39	50	57	63	68
1+45, single-cycle	35	45	52	57	60
1+15, double-cycle	31	40	48	53	56
1+20, double-cycle	29	38	45	49	51
1+30, double-cycle	27	35	42	46	49
1+45, double-cycle	24	32	37	40	42
EA-6B:					
1+15, single-cycle	13	15	20	n/a	22
1+20, single-cycle	13	14	19	n/a	21
1+30, single-cycle	13	14	18	n/a	20
1+45, single-cycle	11	14	17	n/a	19
1+15, double-cycle	10	13	16	n/a	17
1+20, double-cycle	9	12	15	n/a	16
1+30, double-cycle	8	10	14	n/a	15
1+45, double-cycle	8	10	12	n/a	13
E-2C:					
1+45, double-cycle	8	10	11	n/a	11
1+15, triple-cycle	8	10	11	n/a	11
1+20, triple-cycle	8	10	11	n/a	11
1+30, triple-cycle	7	9	10	n/a	10
S-3B ^b :					
1+15, single-cycle	24 / 20	30 / 26	36 / 32	n/a	36 / 33
1+20, single-cycle	23 / 20	29 / 25	35 / 30	n/a	35 / 32
1+30, single-cycle	22 / 19	27 / 23	33 / 28	n/a	33 / 30
1+45, single-cycle	20 / 17	26 / 22	30 / 25	n/a	30 / 27
1+15, double-cycle	- / 15	- / 20	- / 23	n/a	- / 24
1+20, double-cycle	- / 15	- / 20	- / 23	n/a	- / 24
1+30, double-cycle	- / 13	- / 18	- / 20	n/a	- / 21
1+45, double-cycle	- / 11	- / 15	- / 18	n/a	- / 19

a. Each squadron.

b. Tanker mission (approximately 25 percent yo-yo tankers and 75 percent mission/recovery tankers) / (ASW or SSC) missions.

NOTES: (1) Gains for each measure are additive. For example, the capacity realized from accepting a SCR of 85 percent assumes the flight deck is operated 24 hours a day.

(2) See the discussion supporting table 19 in the *Airframe capacity* section of this memorandum for a description of these operating procedures which may increase the sortie generation potential of aircraft.

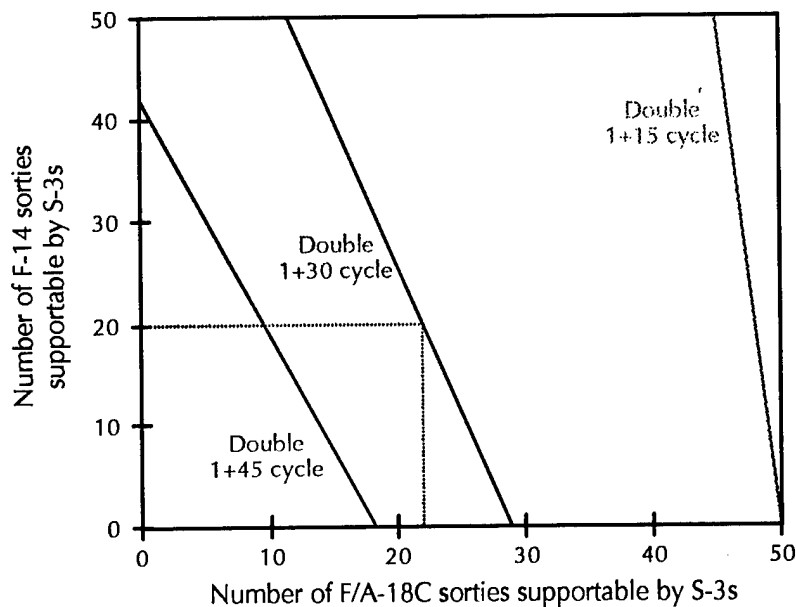
Table 2. Number of strike/fighter sorties supportable by dedicating all air wing S-3s to tanker missions (mission times under 2 hours)

Aircraft type	Single-cycle operations with a cycle time of:		Double-cycle operations with a cycle time of:
	1+30	1+45	1+00
F-14	TNR ^a	TNR	TNR
F/A-18	240	187	108

a. TNR = tanking not required.

NOTE: See the discussion supporting table 18 in the *Airframe capacity* section of this memorandum and the appendix [1] (published separately) for further details on the tanking requirement and the ability of the S-3B to meet the tanking demand.

Figure 2. Number of strike/fighter sorties supportable by dedicating all air wing S-3s to tanker missions (mission times over 2 hours)

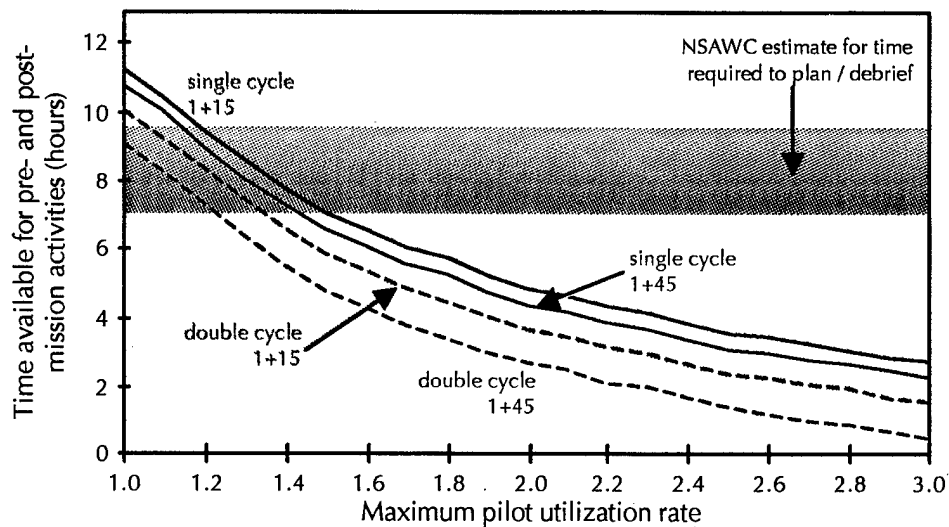


NOTE: See the discussion supporting figure 12 in the *Airframe capacity* section of this memorandum and the appendix [1] (published separately) for further details on the tanking requirement and the ability of the S-3B to meet the tanking demand.

Example of use: All strike/fighters are double-cycled over 1+30 cycles and a minimum of 20 F-14 sorties must be generated. How many F/A-18 sorties can be supported by dedicating all air wing S-3s to tanker missions?

Answer: 22 F/A-18 sorties.

Figure 3. Mission overhead, flight time, and pilot utilization rate



NOTE: See the discussion supporting figure 20 in the *Pilot capacity* section of this memorandum for further details on the use and derivation of this figure.

Table 3. Number of MC aircraft in base case air wing to meet CNO goals

Aircraft	MC goal
F-14A/D	6 / 7
F/A-18C	27
EA-6B	3
E-2	3
S-3B	6
ES-3B	3

NOTE: Data derived from [2].

Table 4. Sortie-generation constraints for example calculation

Constraint	Sorties:		
	F-14	F/A-18	Total strike/fighter
Tanking	no constraint	132	132+
Refueling	n/a	n/a	213 ^a
Pilot availability	17	53	70
Airframe	29	130	159
Sortie generation possible (minimum of all constraints)	17	53	70
Ordnance process constraint (number of sorties configured with air-to-ground ordnance) ^b	9 to 19	51 to 114	60 to 133

a. For the entire air wing.

b. The variation in the number of sorties which can be configured with ordnance is dependent on the type of ordnance loaded.

Table 5. Daily capacity of ordnance crews to ready strike/fighters within an 18-hour flying day

Air-to-ground configuration	F-14 sorties				F/A-18 ^a sorties				Comments
	1+15	1+20	1+30	1+45	1+15	1+20	1+30	1+45	
2 Mk 82 GP or 2 Mk 83 GP	17	18	19	21	35	36	38	40	Loaded manually with hernia bar.
2 Mk 84 GP, 2 Rockeye, or 2 Gator	12	12	13	15	25	26	27	28	Loaded with hoist.
2 JSOW	n/a	n/a	n/a	n/a	25	26	27	28	Loaded with hoist.
2 LGB	7	8	9	9	16	16	17	18	Loaded with hoist. Electrical mating with aircraft required.
2 Maverick, 2 HARM, or 2 SLAM	n/a	n/a	n/a	n/a	16	16	17	18	Loaded with hoist. Electrical mating with aircraft required. Special initialization procedures required.

a. Each squadron.

NOTES: (1) First two launches readied before flight operations begin.

(2) See the discussion supporting table 26 in the *Flight deck capacity* section of this memorandum for further details on the derivation of these estimates.

Table 6. Daily capacity of ordnance crews to ready strike/fighters within a 24-hour flying day

Air-to-ground configuration	Capacity of ordnance crews to configure strike/fighters							
	F-14 sorties				F/A-18 ^a sorties			
	1+15	1+20	1+30	1+45	1+15	1+20	1+30	1+45
2 Mk 82 GP or 2 Mk 83 GP	15	16	17	18	30	31	33	36
2 Mk 84 GP, 2 Rockeye, or 2 Gator	12	13	13	15	21	22	24	25
2 LGB	9	9	9	10	14	14	16	17
2 HARM, 2 Maverick, or 2 JSOW	n/a	n/a	n/a	n/a	14	14	16	17

a. Each squadron.

NOTE: See the discussion of table 30 in the *Flight deck capacity* section of this memorandum for further details on the deviation of these estimates.

What limits firepower capacity?

We found that as the cycle time increases, airframe and aircrew capacities decrease, while the capacity of the flight deck crews to ready aircraft increases. Longer cycle times mean fewer launch opportunities in a day and longer times spent in flight, which is why the airframe and aircrew capacities are reduced. We found that the process of readying aircraft for launch was most restricted by the need to load ordnance on aircraft. The longer cycle times provide longer, uninterrupted periods for ordnance crews to complete loading operations, which is why their capacity increases.

We varied many of the operating conditions to determine their effects on firepower generation. Each change affected our projections of the sortie-generation capacity of the carrier and air wing. We found that changes in the cycle time, the cycle multiple, and the weapon configuration of the aircraft had the greatest effect on which of the three major requirements for sortie generation—aircraft, aircrew, and flight deck operations—was most difficult to meet (table 7). In a real world conflict, these operating conditions will be determined by the objectives of the operation. We found that:

- When F/A-18s are double-cycled, the availability of non-organic tankers to support those aircraft is most important.
- If enough tankers are available, pilot availability is the major shortfall, unless a significant proportion of the F/A-18s are to be loaded with sophisticated munitions.²
- If sophisticated munitions are the weapon of choice, loading them on aircraft is the predominate limiting factor.
- The conduct of non-flying tasks by aircrew diminishes the time available to dedicate to mission execution. The capacity of the pilots to generate sorties can be increased if all of their non-flying tasking is eliminated. If this is done, sortie generation

2. We classify as "sophisticated munitions:" laser-guided bombs (LGBs), Maverick, high-speed anti-radiation missiles (HARMs), and standoff land attack missiles (SLAMs).

increases, but pilot availability still remains the primary constraint when non-sophisticated weapons are employed.

- The time spent preparing for and debriefing a mission reduces the time available for mission execution. If this time can be held to under 5 hours, pilot availability is eliminated as a constraint (as seen in table 7).

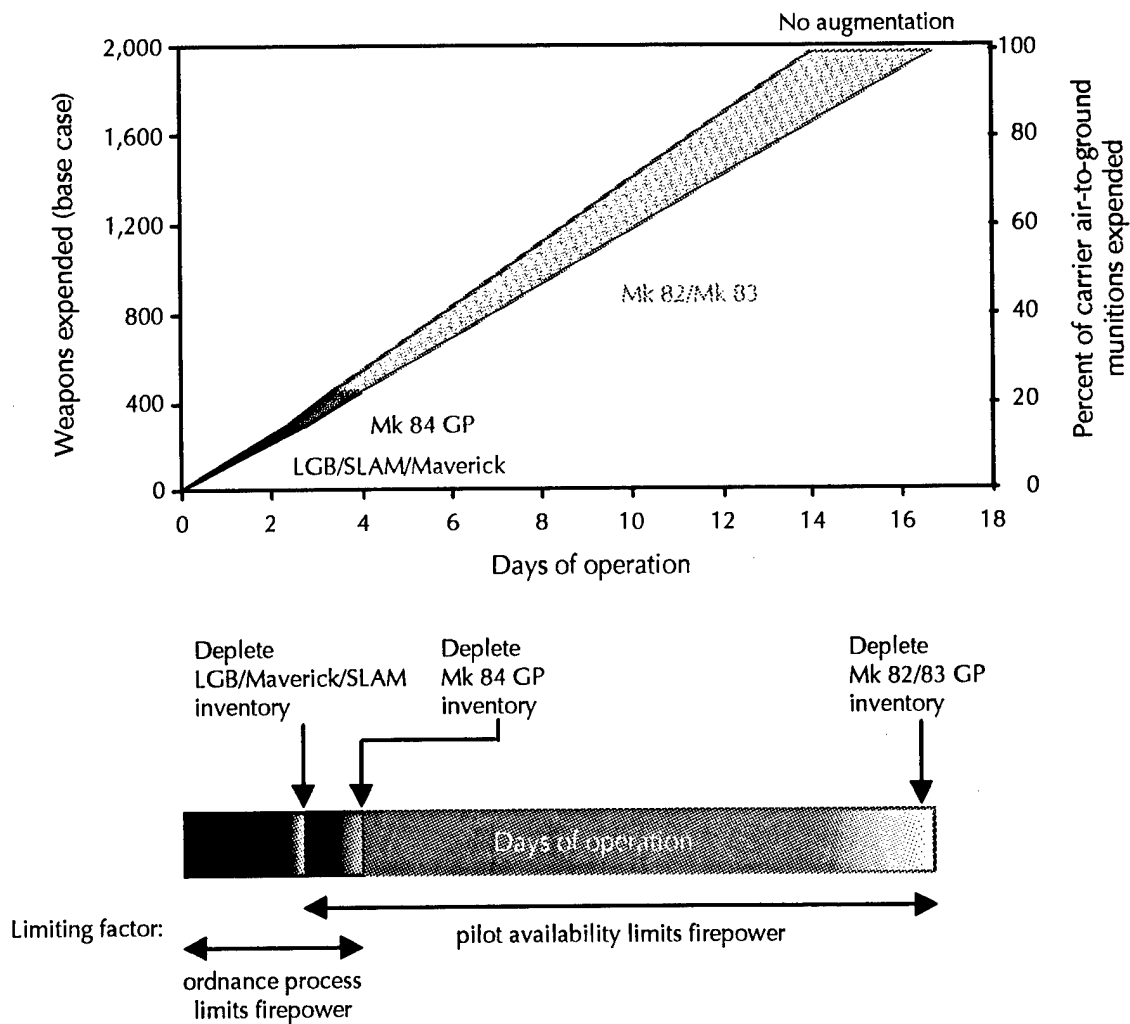
Table 7. Constraints to carrier and air wing sortie generation

Operating condition Strike/fighter weapon carriage	Cycle time, cycle multiple			
	1 + 15, single cycle	1 + 45, single cycle	1 + 15, double cycle	1 + 45, double cycle
Rely solely on organic tankers:				
Mk 82 GP / Mk 83 GP	Pilot	Pilot	Tankers	Tankers
Mk 84 GP / Rockeye / Gator / JSOW	Pilot	Pilot	Tankers	Tankers
LGB / Maverick / HARM / SLAM	Turnaround	Pilot / Turnaround	Tankers	Tankers
Base case assessment:				
Mk 82 GP / Mk 83 GP	Pilot	Pilot	Pilot	Pilot
Mk 84 GP / Rockeye / Gator / JSOW	Pilot	Pilot	Pilot	Pilot
LGB / Maverick / HARM / SLAM	Turnaround	Pilot / Turnaround	Turnaround	Pilot
Eliminate all non-flying tasking of aircrew:				
Mk 82 GP / Mk 83 GP	Pilot	Pilot	Pilot	Pilot
Mk 84 GP / Rockeye / Gator / JSOW	Pilot / Turnaround	Pilot	Pilot	Pilot
LGB / Maverick / HARM / SLAM	Turnaround	Turnaround	Turnaround	Turnaround
Eliminate all non-flying tasking of aircrew. Hold mission preparation / debrief time to under 5 hours:				
Mk 82 GP / Mk 83 GP	Turnaround	Aircraft	Aircraft	Aircraft
Mk 84 GP / Rockeye / Gator / JSOW	Turnaround	Turnaround	Turnaround	Aircraft
LGB / Maverick / HARM / SLAM	Turnaround	Turnaround	Turnaround	Turnaround

In many operational settings, the weapons of choice initially will be the technologically advanced munitions; with these weapons collateral damage tends to be less and weapons effectiveness higher. But it is precisely these munitions that are the most time-consuming with which to configure aircraft. During this initial phase, the manning of

air wing ordnance and carrier weapon departments will determine the firepower of the air wing (figure 4).

Figure 4. Weapons expenditure



Because the number of advanced munitions in a battle group is small, the inventory can be quickly exhausted. At this point, unless replenishment is possible from outside the battle group, munitions that are less technologically advanced but quicker to load must be used. At

this juncture, the number of pilots available to fly the combat missions will constrain the amount of firepower generated (figure 4).

What can be done to increase firepower capacity?

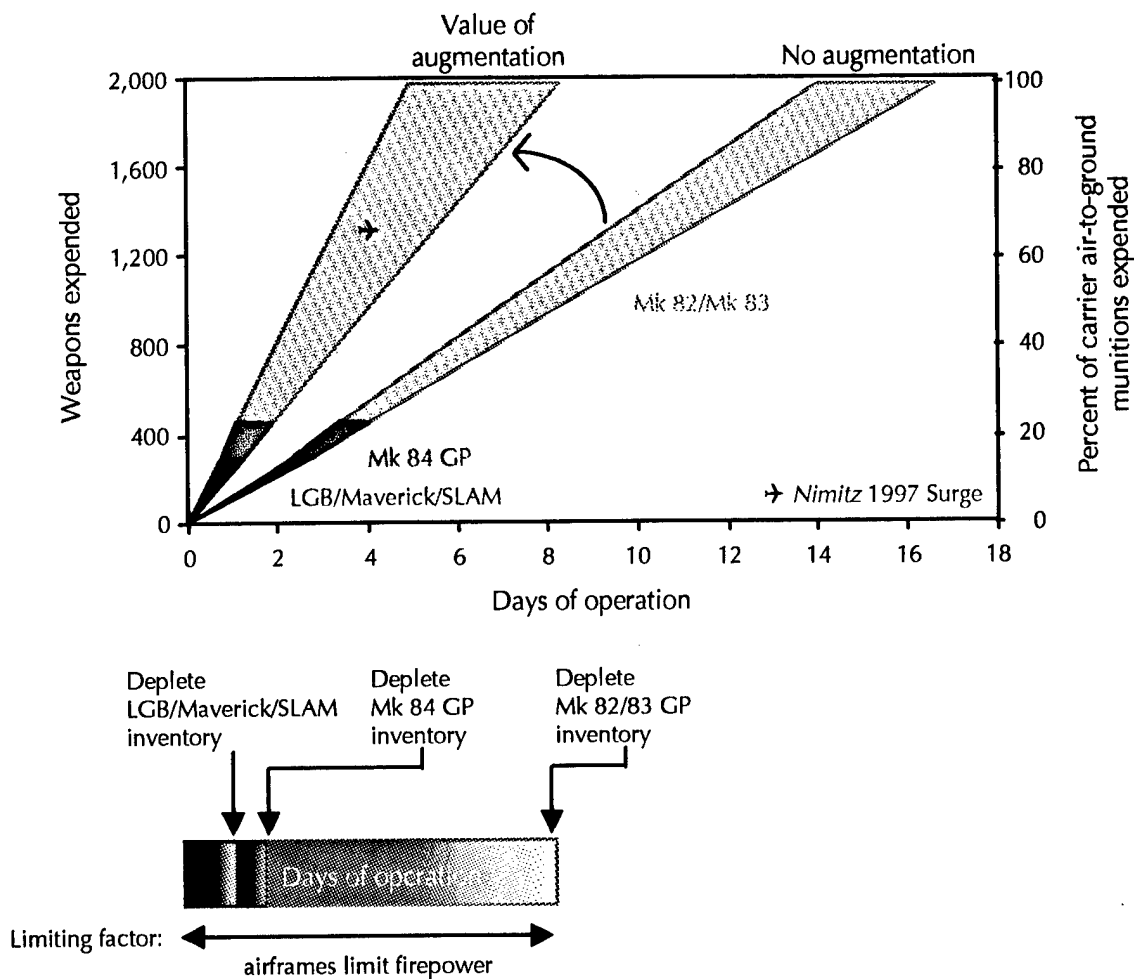
We found that pooling the aircraft, pilots, maintenance personnel, ordnance crews, and tasking of the three F/A-18 squadrons increases the air wing's capacity to meet all three of the major requirements to generate firepower.

The capacity of the flight deck crews will increase if the Navy develops and implements ways to manage the flight deck with greater efficiency as well as reduce the fatigue of the individuals who work there. Measures to reduce the fatigue that occurs during high-intensity flight operations were evaluated during the 1997 USS *Nimitz* Surge [3]. Successful measures evaluated during the 1997 *Nimitz* Surge included:

- Planning for contingencies before high-intensity operations.
- Reducing the planned operating tempo between 0300 and 0500 daily.
- Pausing operations for a few hours before high-intensity flight operations to ensure personnel were rested.
- Cancelling cleaning stations, inspections, and most administrative meetings.
- Suspending man overboard and fire drills.
- Opening galleys 24 hours a day and providing hot food at satellite feeding stations in various work centers.
- Limiting the use of the IMC to only critical announcements.
- Permitting personnel to take naps in safe places near their work centers.

The most straightforward means to increase the capacity of the flight deck crews (and other personnel) is to augment them with individuals to share their workloads. What is the potential gain for augmenting? Our assessment indicates that the rate of firepower generation could potentially double (figure 5).

Figure 5. Increase in firepower with sufficient personnel augmentation



If the carrier and air wing can be augmented with personnel, the highest priority should be placed on augmenting air wing ordnance crews, carrier weapons department personnel, and air wing aircrews. Nevertheless, questions concerning how many individuals, their necessary qualifications, and how they could be quickly and efficiently integrated into carrier and air wing operations must be answered. These questions were addressed in the 1997 USS *Nimitz* surge operation.

Addressing the number and qualifications of the augmentees, USS *Nimitz* personnel determined which individuals were most at risk for fatigue (table 10). Of the approximately 4,700 personnel assigned to USS *Nimitz* and Carrier Air Wing Nine (CVW-9), 60 percent were considered to be at risk. Anticipating this need, Commander, Naval Air Forces Pacific (CNAP) sent about 250 individuals to USS *Nimitz* to assist with the surge (table 11).

Table 8. USS *Nimitz* and CVW-9 initial estimate of the population most at risk for fatigue during high-intensity flight operations

	Population at-risk	Personnel groups
Carrier department		
Air	457	All
Engineering	20	O2N2 plant operators, elevators, catapult steam operators, A&O
Safety	9	All
Operations	36	Controllers, CTAPS operators, intelligence specialists
AIMD	390	All
Weapons	223	All
Navigation	23	All
Air wing	1,728	All
Total	2,886	

Table 9. Augmentees for the 1997 USS *Nimitz* Surge

Command	Unit	Position	Rank/Rate	Augmentees	
				Active	Reserve
CVW-9	F-14 squadron	Pilots	O-4, O-3	1	1
CVW-9	F-14 squadron	RIOs	O-4, O-3	5	1
CVW-9	F/A-18 squadron	Pilots	O-4, O-3	7	
CVW-9	F/A-18 squadron	Pilots	O-4, O-3	7	
CVW-9	F/A-18 squadron	Pilots	O-4, O-3	7	
CVW-9	F/A-18 squadron	Ordnance personnel	AOAN-AOC	22	8
CVW-9	F-14 squadron	Ordnance personnel	AO3-AOCS	8	
CVW-9	F/A-18 squadron	Plane captains	AN	12	
CVW-9	F-14 squadron	Plane captains	AN	2	
CVW-9	E-2 squadron	CICOs	O-3	4	
CVW-9	E-2 squadron	Electronics technicians	AT2, AT3	2	
CVW-9	E-2 squadron	Aviation machinists	AD3, AD1	3	
CVW-9	E-2 squadron	Aviation electricians	AE3	2	
CVW-9	HS squadron	Aviation machinists	AD1, AD2	2	
CVW-9	Staff	Landing signal officers	O-3	5	
CVW-9	Staff	Air intelligence officers	O-2, O-3	3	
CVW-9	Staff	Strike cell planners	O-1 through O-6	6	4
USS <i>Nimitz</i>	Air Dept.	Air Boss	O-5	1	
USS <i>Nimitz</i>	Air Dept.	Mini Boss	O-5	1	
USS <i>Nimitz</i>	Air Dept.	Catapult officers	O-3	2	
USS <i>Nimitz</i>	Air Dept.	Aircraft directors	ABH3, ABH2, ABH111	12	4
USS <i>Nimitz</i>	Air Dept.	Aviation boatswain's mates	AN, ABH3	20	
USS <i>Nimitz</i>	Air Dept.	Fueling personnel	ABF3, AN	12	1
USS <i>Nimitz</i>	Air Dept.	Tower operators	ABH3, AN	5	
USS <i>Nimitz</i>	Air Dept.	V-2 personnel	ABE3		1
USS <i>Nimitz</i>	Air Dept.	Flight deck caller	O-4		1
USS <i>Nimitz</i>	Weapons	Ordnance personnel	AO3, AO2, AOC	10	6
USS <i>Nimitz</i>	Operations	Assistant Air Operations Officer	O-5	1	
USS <i>Nimitz</i>	Operations	Assistant Strike Operations Officer	O-4	1	
USS <i>Nimitz</i>	Operations	CTAPS Administrator	O-5		1
USS <i>Nimitz</i>	Operations	CTAPS operators	AC2, AC3	2	
USS <i>Nimitz</i>	Operations	Air traffic controllers	AC1	4	
USS <i>Nimitz</i>	Operations	Air intercept controllers	OS1, OS2	4	
USS <i>Nimitz</i>	Operations	Intelligence officers	O-3, O-4	4	
USS <i>Nimitz</i>	Operations	Intelligence specialists	IS1, IS2, IS3	4	
USS <i>Nimitz</i>	Operations	U.S. Air Force intelligence debriefers		2	
USS <i>Nimitz</i>	Operations	U.S. Marine Corps liaison		1	
USS <i>Nimitz</i>	Operations	Operations specialist	OS2		1
USS <i>Nimitz</i>	Operations		O-4		1
USS <i>Nimitz</i>	AIMD	Aviation support technicians	AS3, AS2, AS1	10	1
USS <i>Nimitz</i>	AIMD	Aviation electronics technicians	AT3, AT2		9
USS <i>Nimitz</i>	AIMD	Aviation electricians	AE3, AE1		2
USS <i>Nimitz</i>	AIMD	Structural mechanics	AMS3, AMSAN		8
USS <i>Nimitz</i>	AIMD	Aviation machinists	AD3		2
USS <i>Nimitz</i>	AIMD	Maintenance administrator	AZ3		1
USS <i>Nimitz</i>	AIMD	Hydraulics mechanic	AMH2		1
USS <i>Nimitz</i>	AIMD		O-4		1
USS <i>Nimitz</i>	Medical	Hospital corpsman	HM2		1
USS <i>Nimitz</i>	Supply		SN		1
USS <i>Nimitz</i>	Supply	Aviation storekeepers	AK3, AKAN		6
Totals				194	63

Based on the lessons of the 1997 *Nimitz* Surge, we refined the number and qualifications of augmentees required to support high-intensity flight operations conducted 24 hours a day (table 12). This estimate is preliminary and should be further refined as the fleet gains additional insight into its capacity to generate firepower and as new systems enter the fleet.

A key attribute of augmentees is that they come on board with the necessary qualifications, which is especially important during a crisis, when there is no time to conduct training. This requirement poses a potential problem for augmenting aircrew—there may not be enough carrier-qualified aircrew available in non-deployed status to meet the anticipated need. However, this may not be as difficult a problem as it seems initially. Our findings indicate that in the initial two days of operations, the ordnance process will constrain sortie generation. During this period, augmentee aircrew could become carrier-qualified and gain familiarity with carrier and air wing standard operating procedures (SOPs). In addition, during this period the aircrew augmentees could help resident aircrew plan, targeteer, prepare strike mission packages, coordinate the tanking plans, assess bomb-damage assessment (BDA), and coordinate the administrative functions supporting air interdiction and close air support (CAS) execution. Thus, it may not be necessary for the augmentee aircrew to be carrier-qualified when they arrive on board—merely current on the blocks of aircraft resident on board the carrier.

The fleet is developing ways to ease the integration of the augmentees into the carrier and air wing. For example:

- Individuals who may likely be chosen as augmentees are being included in USS *Constellation*'s pre-deployment workups. If successful, this may allow augmentees to become familiar with the carrier's SOPs, instill confidence in the resident personnel that the augmentees can contribute, and allow the augmentees to be "ready on arrival."
- The Navy is considering reviewing fleet practices to identify those that would benefit from standardization or codification. The 1997 USS *Nimitz* Surge demonstrated that when fleet-wide practices were in place—such as the aviation community's

acceptance of NSAWC procedures—integration of the augmentees was seamless. Where such procedures were absent, full utilization of augmentees was delayed. In situations where standardization is not practical, codification of SOPs would allow augmentees to review the carrier's and air wing's specific SOPs before arriving on board.

- The Navy is considering whether to create a standing augmentation cell resident in the United States. This cell would augment carrier battle groups in any operational theater during times of crisis. The composition of the deployed cell would be tailored to the real world situation and requirements.

We also found that augmenting the strike/fighter aircraft on board has limited utility. The reliability and ease of repair of the F/A-18 makes satisfying the requirement for MC F/A-18s easy to meet. Augmenting an air wing with additional F/A-18 aircraft will enhance firepower capacity only after steps have been taken to ensure the other two requirements—pilots are available to fly the aircraft and those aircraft can be readied in time for launch—can be met. When mission objectives require F/A-18s to be double-cycled, the F/A-18's dependence on non-organic tankers can be reduced by increasing the number of S-3B on board. Increasing the number of EA-6Bs on board increases the tactical flexibility available to the carrier battle group when confronting an enemy with a sophisticated air defense network.

We summarize in table 8 the ways the Navy could modify its standard procedures to increase its firepower capacity. We also looked at how sortie generation might fall if operations were not conducted as in the base case (table 9).

Table 10. Recommended manning levels for augmented billets during high-intensity, 24-hour flight operations

Job category	Manning level
Air wing	
Aircrew	Command determination of pilot utilization rate is required. Figure 3 is a nomogram for determining pilot utilization rate based on expected mission planning, flight, and debrief times.
Plane captains	136 required (manning during 1997 <i>Nimitz</i> Surge).
O-level maintenance	Augment F-14 squadron to 30 percent over BA; augment other squadrons between 13 and 18 percent over BA. Further, recommend each strike/fighter squadron augmented by additional two to four experienced personnel capable of trouble-shooting aircraft.
CAG LSOs	Minimum of 9.
Ordnance load-ing personnel	Minimum of 30 (40 for operating tempos higher than demonstrated during 1997 <i>Nimitz</i> Surge) for each F/A-18 squadron. Minimum of 36 (56 for operating tempos higher than demonstrated during 1997 <i>Nimitz</i> Surge) for the F-14 squadron. Manning for other squadrons to be determined.
Carrier	
Air Department	
V-1 division	Minimum of 212, the wartime (M+1) manning requirement.
V-2 division	Minimum of 215, the wartime (M+1) manning requirement.
V-3 division	With few aircraft in the hangar bays, job not as difficult as during normal operations. No augmentation required.
V-4 division	122 personnel adequate (manning during 1997 <i>Nimitz</i> Surge). Some reduction may be possible.
AIMD	45 aviation support technicians (slightly more than the manning during 1997 <i>Nimitz</i> Surge). For operations lasting longer than a week, however, at this manning the backlog of work will grow and potentially affect availability of aircraft.
Operations Department	
OSPC	Include in future high-intensity operations. Fourteen officers and three dedicated enlisted support required.
CVIC	Man to BA with additional seven officers and ten air intelligence specialists (exceeds manning of 1997 <i>Nimitz</i> Surge).
Strike Operations	Augment with one Assistant Strike Operations Officer and, if carrier is designated as a level-one JFACC, four qualified CTAPS operators. When operations require coordination with ARG/MEU or U.S. Air Force units, presence of U.S. Marine Corps and U.S. Air Force liaison officers invaluable.
Air Control	Two watch teams, each composed of 18 personnel (5 supervisory, 6 console operators, 5 status board keepers, 2 plotters/record keepers) adequate (manning during 1997 <i>Nimitz</i> Surge).
Weapons Department— ordnance assembly personnel	215 personnel (ninety percent of 1997 <i>Nimitz</i> Surge manning) is sufficient.
Individuals in command positions	
Air Operations Officer, Air Boss, Mini Boss	Provide augmentees for each position. Ensure operating procedures are agreed upon by all parties.
All others	Delegate chosen from resident staff. Provide augmentation to assist delegate.

NOTE: Because the number of individuals currently on board may differ from carrier to carrier, our recommendations are cast in terms of the total manning required, including resident personnel.

Table 11. Ways to increase firepower capacity over that of the base case

Ways to increase capacity if limited by:		
Airframes	Aircrew	Flight deck operations
Conduct flight operations for 24 hours a day	Eliminate non-flying tasking (including assignments as liaison officers) of aircrew	Ensure sufficient number of operable gas-powered weapons hoists (HLU-196) are available
Accept air plans with an anticipated SCR ^a of at least 85 percent	Pool tasking to F/A-18 pilots	Employ ORM measures to reduce fatigue of flight deck crews and carrier ordnance department
Employ ORM ^b measures to reduce fatigue of O-level ^c maintenance personnel	Reduce the time aircrew spend preparing for a mission and in debriefing	Pool ordnance crews from F/A-18 squadrons
Treat air wing F/A-18s as a pooled asset	Employ ORM measures to reduce fatigue	Augment air wing ordnance crews and carrier air, operations, and weapons departments
Preemptively request spare parts and consumables from depot level	Tap other qualified aviators on board	
Augment O-level maintenance personnel	Reduce crew rest	
Augment aircraft	Augment aircrew and support personnel	

a. SCR = sortie completion rate.

b. ORM = operational risk management.

c. O-level = organizational level.

Table 12. Conditions that reduce firepower capacity below that of the base case

Factors that can reduce the sortie capacity of:		
Airframes	Aircrew	Flight deck operations
Insufficient tanker support (required only when aircraft are double-cycled or cycle times are longer than 1+20)	Air wing aviators manned to less than BA ^a	Air wing ordnance crews and carrier air, weapons, and operations department not manned to BA
Insufficient ECM ^b support (when required by threat)	Aircrew utilization rates below cap set by battle group commander	Strike/fighters configured with larger ordnance loads
Conduct of α -strikes	Administrative tasks of aircrew cannot be postponed	Gun loading conducted
Extended duration of operations	Fatigue and combat stress force a reduction in pilot utilization rate	Deck-edge elevator use restricted
Attrition or accidents	Fewer pilots available due to greater non-flying tasking, sickness, or combat loss	Low availability of gas-powered weapons hoists (HLU-196)
Elevator use restricted during flight operations	Bad weather	Reconfiguration of aircraft launchers and rails required frequently
PMS ^c operations interrupt or degrade flight operations		FOD ^d walkdowns conducted frequently
MC rates at beginning of operation lower than CNO goals		Cycle times less than 1+15
Cannibalization not always conducted		Flight operations conducted for significantly longer than 18 hours a day
Off-ship LRT ^e high		Carrier conducts replenishment
O-level and I-level ^f maintenance manned to less than BA		Barrier landing executed
Bad weather		Flight-deck density high
		HERO ^g conditions present
		Execution of air plan with an anticipated sortie completion rate of at least 85 percent
		Carrier must generate wind over deck
		Bad weather

a. BA = billets authorized.

b. ECM = electronic countermeasures.

c. PMS = preventative maintenance and servicing.

d. FOD = foreign object damage.

e. LRT = logistics response time.

f. I-level = intermediate level.

g. HERO = hazards of electromagnetic radiation to ordnance.

Base case

The base case frames our results. Our estimates of the capacity of the airframes, the aircrew, and the carrier and air wing's ability to launch, recover, and ready aircraft for launch rely on the characteristics of the base case. We first discuss those characteristics of the base case that influence all three requirements (aircraft, aircrew, and flight deck) for the creation of sea-based air power. We then discuss those characteristics that pertain solely to a single requirement. Finally, we discuss how a carrier and air wing's capacity to generate air power changes when the operational situation differs from the base case.

We modelled the base case after operational employment typical of current deployed carrier battle groups with standard resources and support available, as follows:

- *Carrier class.* We used the characteristics of a *Nimitz*-class carrier: the size of the flight deck (the equivalent of 80 F/A-18C spots), the locations of the fueling stations and the deck-edge and ordnance elevators, the size of the bomb farm, the ease and speed of building and transferring ordnance to the flight deck, and the ease and speed of exchanging aircraft between the flight and hangar decks.
- *Air wing composition.* Table 13 shows air wing composition. Because the number of pilots on board a carrier varies over a deployment as crews are coddled to and from land, we used the nominal numbers of pilots as shown in table 13 as our base case manning. This estimate agrees with the number of pilots in Carrier Air Wing Three (CVW-3) squadrons when they deployed in November 1998.
- *Air wing structure.* The F/A-18s are assigned to three squadrons; other aircraft types are assigned to individual squadrons. Each squadron has its own command structure, aircrew,

maintenance personnel, and ordnance-loading crews. Tasking is provided to each squadron separately.

Table 13. Air wing composition for the base case

Type	Number of pilots on board	Number of aircraft on board	Spot factor	Deck multiple	Pilot-to-aircraft ratio
F-14	14	10	1.32	13.20	1.4
F/A-18C	51	36	1.00	36.00	1.4
EA-6B	7	4	1.23	4.92	1.7
E-2C	6 ^a	4	1.71	6.84	1.5
S-3B	12	8	1.25	10.00	1.5
ES-3	4	2	1.25	2.50	2.0
C-2	n/a	2	1.71	3.42	n/a
H-60	n/a	6	0.51	3.06	n/a

a. Mission commanders.

- *Carrier and air wing manning.* The complements of the carrier's air and weapons departments and the air wing's squadron maintenance and ordnance divisions are at billets authorized (BA). While this is the objective for every deployment, recent budgetary pressures have increased the difficulty of manning to BA.³
- *Preventative maintenance and servicing (PMS).* PMS schedules for aircraft and ship aviation systems are current, but no effort to preemptively conduct PMS before high-intensity flight operations was made. In the base case, scheduled maintenance can be deferred, conducted between recovery and launch of aircraft, or performed outside flight quarters.
- *Duration of flight quarters.* Flight operations are conducted for 18 hours each day. Flight quarters are set about two hours before the first launch and continue about one hour after the last recovery. Since the Vietnam conflict, carriers have rarely conducted high-intensity flight operations involving large

3. For example, VF-32 Maintenance Department deployed in November 1998 with 20 Airmen, while their BA is 38.

expenditures of ordnance for more than 18 hours a day. A notable exception to this was the 1997 *Nimitz* Surge, during which flight operations were conducted non-stop for 98 hours and strike/fighters delivered over 1,300 Mk 80-series bombs.

- *Operating tempo.* The objective of the carrier and air wing is to generate sorties at a uniform rate throughout the flight day. Cyclic operations are employed.⁴
- *Elevator usage.* The deck-edge elevators are used extensively during flight quarters. This is in contrast to typical carrier procedures during low-intensity, peacetime operations. Even in past wartime operations, including Operation Desert Storm, elevator runs were rarely made concurrent with high-intensity flight operations. In the past few years, however, this restriction has been identified as a major constraint to sortie generation and now whenever large numbers of sorties are needed, the fleet routinely operates elevators during flight operations.
- *Weapons in the carrier magazine.* We used a nominal carrier load-out as described in [4]. This agrees with the loadouts of USS *Nimitz*, USS *Stennis*, and USS *Enterprise* during their recent deployments.
- *Supply.* The complement of spare parts and consumables on board the carrier is typical of that of deployed carrier battle groups. We used a nominal carrier battle group aviation spare parts allotment as represented by that of the USS *Nimitz* battle group during its 1997-98 deployment.
- *Logistic response time (LRT).* The total wholesale LRT for high-priority items is six days and parts are requested only as needed.⁵ Currently, this time period is typical of the average

4. To manage a flight deck efficiently, carriers normally conduct operations in controlled time periods, or cycles, which typically range in length from 1 hour and 45 minutes (1+45) to as low as 1 hour (1+00). In single-cycle operations, aircraft launch in one cycle and recover during the next cycle. Similarly, double-cycled aircraft launch in one cycle, remain airborne throughout the next cycle, and recover during the following cycle.

wholesale LRT for high-priority items requested by carriers operating in the Persian Gulf and is also representative of the experience of carriers during Operation Desert Storm.

- *Environment.* Weather and sea state do not impede flight operations.

Conditions pertaining to airframe capacity

The base case contains the following additional assumptions, which pertain solely to our estimation of the availability of the airframes:

- *Aircraft mission-capable (MC) rates.* The specific MC rates by aircraft at the beginning of high-intensity flight operations are shown in table 14. As long as an aircraft is MC for its assigned mission, it will be flown.

Table 14. CNO goals for MC rates by aircraft type

Aircraft	MC goal
F-14A/D	0.65 / 0.71
F/A-18C	0.75
EA-6B	0.73
E-2	0.70
S-3B	0.70
ES-3B	0.70

Source: [2].

- *Cannibalization policy.* Squadrons actively cannibalize aircraft for needed parts. Squadron maintenance personnel cannibalize weapons replaceable assemblies (WRAs) for both supply and operational reasons: because there are no ready-for-issue (RFI) replacement WRA parts available (lack of parts in supply); or

5. LRT is a measure of the carrier's supply system and the logistics system off the carrier. It is the total time from when a squadron requests a replacement part to when it receives the part. The O-level and I-level turnaround times (TATs) constitute the on-ship portion of LRT.

because there is not enough time before that aircraft is to launch for them to get the part from supply and perform the remove-and-replace action (operational). Cannibalizing WRAs at the O-level is one way to maximize squadron readiness rates. By consolidating as many gripes as possible into the fewest number of airframes possible, maintenance personnel can keep readiness rates at their maximum. Without doing this, aircraft readiness could be quite low during high-intensity flight operations or when supply inventories run low. The cost for this policy is an increase in the workload of the maintenance personnel—cannibalization doubles the number of removal and installation actions necessary.

- *Sortie-completion rate (SCR).* Air plans are designed with an anticipated SCR of at least 95 percent.
- *Primary mission tasking of aircraft.* Each aircraft type is certified to conduct certain operational missions, provided specific avionics systems are operational [2]. In estimating airframe capacity, we used the frequency of failure and the time required to repair the avionics systems critical for aircraft to perform the missions listed in table 15. Other missions that depend on a different set of avionics systems being functional may result in different projections of sortie-generation capability.

Conditions pertaining to aircrew capacity

Our base case also contains the following additional assumptions, which pertain solely to our estimation of the capacity of the aircrews to fly combat missions:

Table 15. Missions of aircraft

Aircraft	Mission
F-14	Composite force air superiority (CFAS) Escort / Strike TARPS
F/A-18	CFAS Escort / Strike Suppression of enemy air defenses (SEAD)
EA-6B	SEAD Electronic countermeasures (ECM) support
E-2	Command and control
S-3	Antisubmarine warfare (ASW) Surface search and coordination (SSC) Tanker
ES-3	Electronic surveillance / reconnaissance

- *Aircrew qualifications.* All aircrew in the air wing are day and night carrier-qualified.
- *Aircrew availability.* Not all pilots will be available for flight duty at all times—some may be on medical flight status, others may be performing Liaison Officer (LNO) duties or standing watch. For the base case, we assume that no aircrew are on medical flight status; each strike/fighter squadron and the EA-6B squadron are tasked to provide one LNO whose duty assignment is off ship; and each squadron provides one representative to primary flight control (pri-fly) and to the Landing Signals Officer (LSO) platform during flight operations (which are conducted 18 hours each day.) This allocation of additional duty is in close agreement with [4], which proposes a nominal value of 10 percent of the squadron's aircrew lost to these additional duties. These duties may be shared among the aviators in the squadron, which places a relatively heavier workload on the F/A-18 pilots than the pilots in the other squadrons.
- *Administrative work.* We assume that all routine administrative work is postponed until after high-intensity flight operations have ceased.
- *Crew rest of 9 hours a day.* Under this assumption, the 18-hour flying day, which will be a key factor in the capacity of the

airframes to generate sorties, will not significantly influence the capacity of the aircrews.

- *Man-ups to sorties flown ratio.* Some man-ups of aircraft do not result in sorties—spares may not fly or aircraft can go down before launch. We use data from the 1997 *Nimitz* Surge to estimate that 80 percent of the F-14 man-ups and 95 percent of the man-ups of other aircraft result in sorties flown. These two values reflect the difference in the reliability of the F-14 and other aircraft.

Conditions pertaining to flight deck operations

The following additional assumptions about the base case pertain solely to our estimation of the ability of the carrier and air wing personnel to launch, recover, and ready aircraft:

- *Availability of weapons hoists and tractors.* The carrier has the typical complement of weapons hoists and tractors on board; specifically, there are 18 HLU-196 gas-powered weapons hoists and 14 tractors. This agrees with the complement on board USS *Nimitz* and USS *Stennis* during their recent deployments.
- *Load plan.* The load plan calls for two air-to-ground bombs to be the standard strike aircraft configuration. These loadouts are recommended in [4] and are recoverable loads.⁶ Because the load plan does not call for a wide variety of weapon configurations, the ejection racks on aircraft do not need to be reconfigured. Guns are not used.
- *Preparation for the first launch.* Aircraft for the first two launches are readied and spotted on the flight deck before each period of flight operations.

6. An F/A-18 with two drop tanks, a targeting forward-looking infrared (FLIR) sensor, air-to-air weapons, and 3,000 lbs of JP-5 can recover with two 1,000-lb weapons and remain under its maximum trap weight for day and night operations, precluding the need to jettison ordnance brought back to the carrier.

Airframe capacity

The capacity of airframes to generate sorties is based on two factors:

- The number of MC airframes on the flight deck.
- The number of times the airframes are scheduled to fly.

These two factors are neither independent nor constant over the course of an operation; they are constrained by available resources, and influenced by choices made by the operational commander to accomplish the tasking of the carrier battle group. For example, as aircraft are scheduled and flown, they break, thereby reducing the MC rate. The O-level and I-level maintenance personnel counteract this by repairing aircraft, but in so doing, draw down the supplies of spare parts and servicing consumables. If MC rates fall, the air plan may be adjusted to reduce the number of aircraft scheduled to fly.

For the base case, we assume for each aircraft type the number of MC airframes is initially the number on board (table 13) multiplied by the CNO goals for MC rates (table 14). Normally, the MC rates fall as flight operations are conducted.

The number of times aircraft are scheduled to fly is determined by the air plan, which is in turn determined by the objectives of the carrier battle group's mission. The air plan, which specifies the cycle time and cycle multiple of aircraft, is the translation of the mission tasking into asset allocation and use. The cycle times and cycle multiples balance the flight times required of all aircraft to perform their individual tasks. The air plan is inherently sub-optimal for tasking to individual aircraft, but designed to accommodate the tasking of the air wing as a whole. Further, the air plan also reflects the aircraft's requirements for tanking and electronic warfare support.

The air plans we considered are composed of cycles that are exclusively 1+15, 1+20, 1+30, or 1+45 in duration. We considered options

where aircraft are single- or double-cycled, or, in the case of the E-2, triple-cycled.

Capacity of airframes in the base case

We used simulation modeling [5 and 6], coupled with an extensive database on U.S. Navy fixed-wing aircraft maintenance actions,⁷ to estimate airframe sortie-generation capacity. Our results are summarized in table 16 and graphed in figures 6 through 11.⁸ The estimates shown in table 16 should be achievable at the 50 percent confidence level. This means that half the time sortie generation values will be above these estimates and half the time sortie generation will be below these estimates. Tables providing the estimates of expected sortie generation attainable at the 90 percent and 10 percent confidence levels can be found in the appendix [1] (published separately). Figures 6 through 11 graph the probability of achieving a number of sorties in an 18-hour flying day. Our results fall under the following caveats:

- These estimates are unconstrained by the need to have aircrew fly the aircraft or for the aircraft to be readied for launch.
- Observed performances should be expected to vary (both above and below) the model's estimates of average sortie-generation capacity.
- The F-14 capacity is significantly higher than evidenced during recent fleet experiences, in particular during the 1997 *Nimitz* Surge. The historical AV3M data of the F-14 used in the simulation modeling are based on deployments in the 1980s and early and mid-1990s. The F-14, especially the A variant, is an aging airframe and these data may no longer be representative of current deployed F-14s. As a result, our assessment of the sortie-generation potential of the F-14 is probably optimistic.

7. These data include the frequency of failure and the time required to return the aircraft to MC status.

8. CNO has recently decided to retire the ES-3. Accordingly, we do not include estimates for ES-3 sortie-generation capacity.

Table 16. Airframe capacity at the 50 percent probability level for each squadron in the base case

	Single-cycle				Double-cycle			
	1+15	1+20	1+30	1+45	1+15	1+20	1+30	1+45
F-14	27	26	25	23	21	20	19	17
F/A-18C ^a	43	42	39	35	31	29	27	24
EA-6B	13	13	13	11	10	9	8	8
E-2C	-	-	-	-	8 ^b	8 ^b	7 ^b	8
S-3B ^c	24 / 20	23 / 20	22 / 19	20 / 17	- / 15	- / 15	- / 13	- / 11

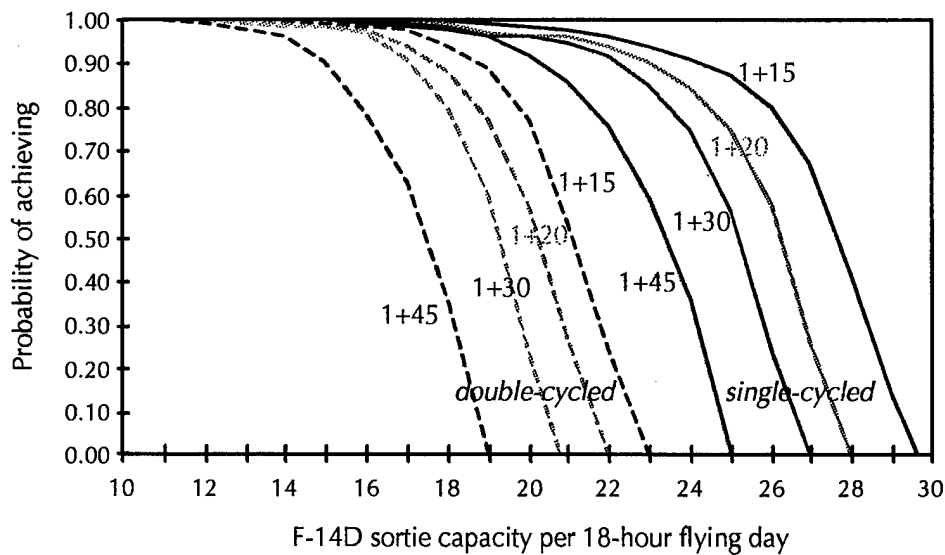
a. Each squadron.

b. E-2s were triple-cycled over these cycle times.

c. Tanker mission / (ASW or SSC) missions. For the tanker mission, approximately 75 percent of the S-3 sorties are single-cycle, mission/recovery tankers and the remaining S-3b tanker sorties are recovered on the same cycle as they are launched (yo-yo tankers).

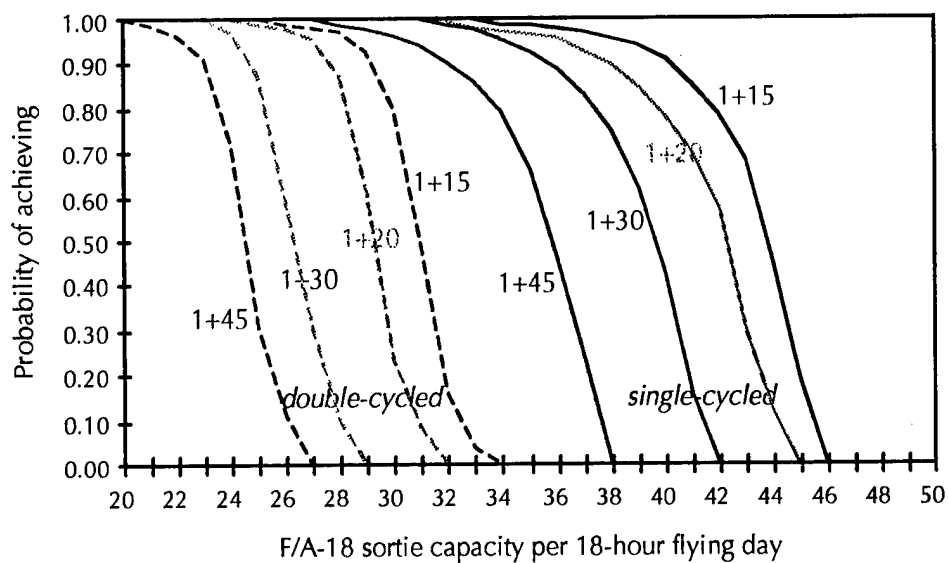
NOTE: Values in this table are for a 50 percent confidence level. This means that half the time sortie generation values will be above these estimates and half the time sortie generation will be below these estimates. Tables providing the estimates of the 90 percent and 10 percent confidence levels for the airframe capacity can be found in the appendix [1] (published separately).

Figure 6. F-14D airframe capacity for the conduct of CFAS, strike, and TARPS missions



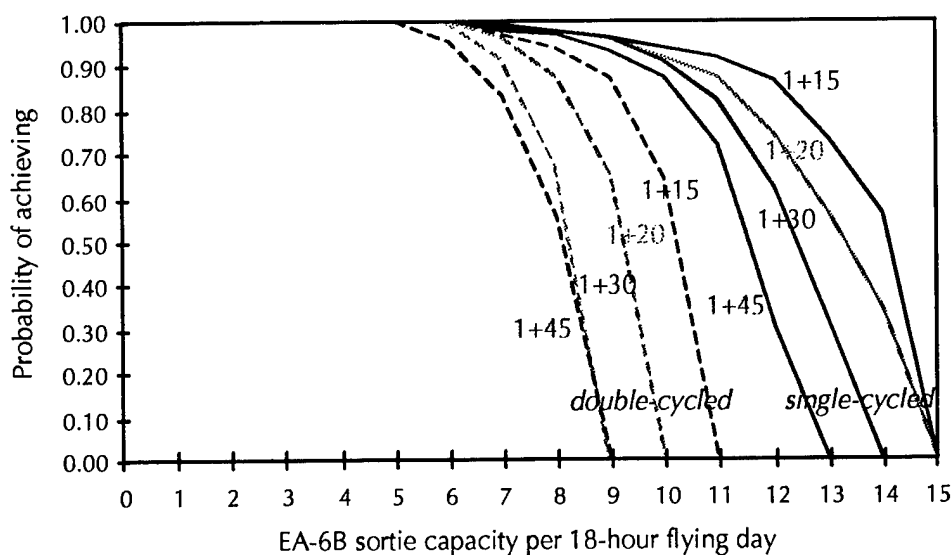
NOTE: 7 of 10 F-14Ds MC at the beginning of flight operations.

Figure 7. F/A-18 airframe capacity for the conduct of CFAS, strike, and SEAD missions



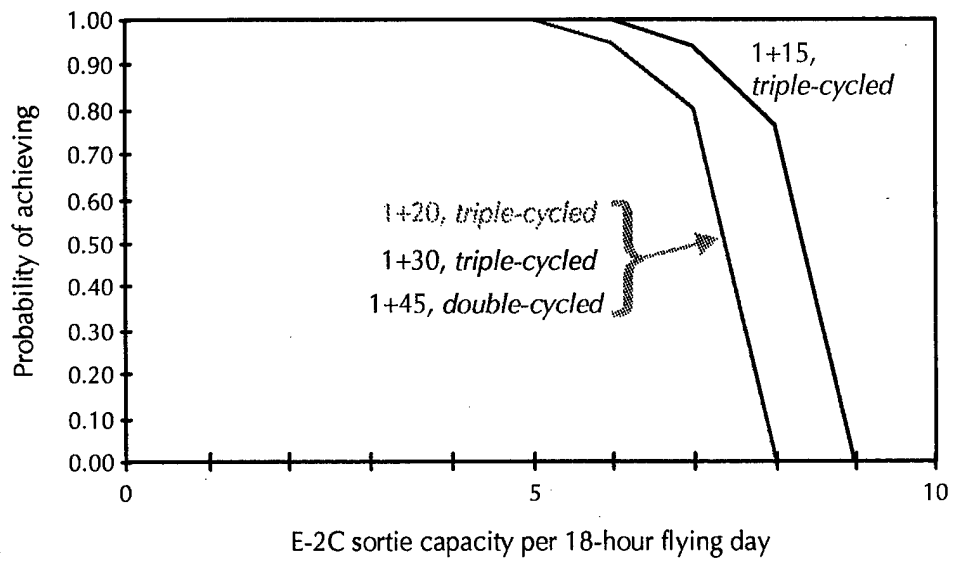
NOTE: Each squadron; 9 of 12 F/A-18s MC at the beginning of flight operations.

Figure 8. EA-6B airframe capacity for the conduct of SEAD and ECM missions



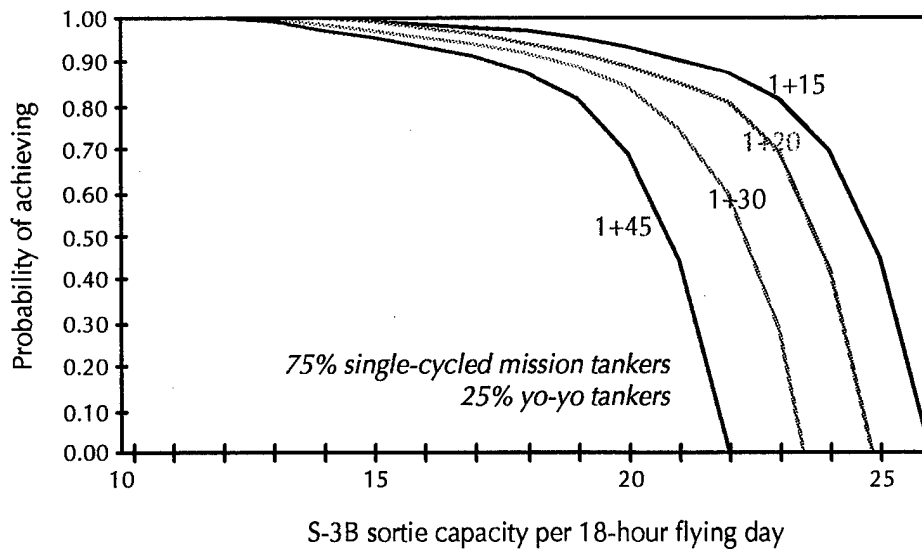
NOTE: 3 of 4 EA-6Bs MC at the beginning of flight operations.

Figure 9. E-2C airframe capacity for the conduct of command and control missions



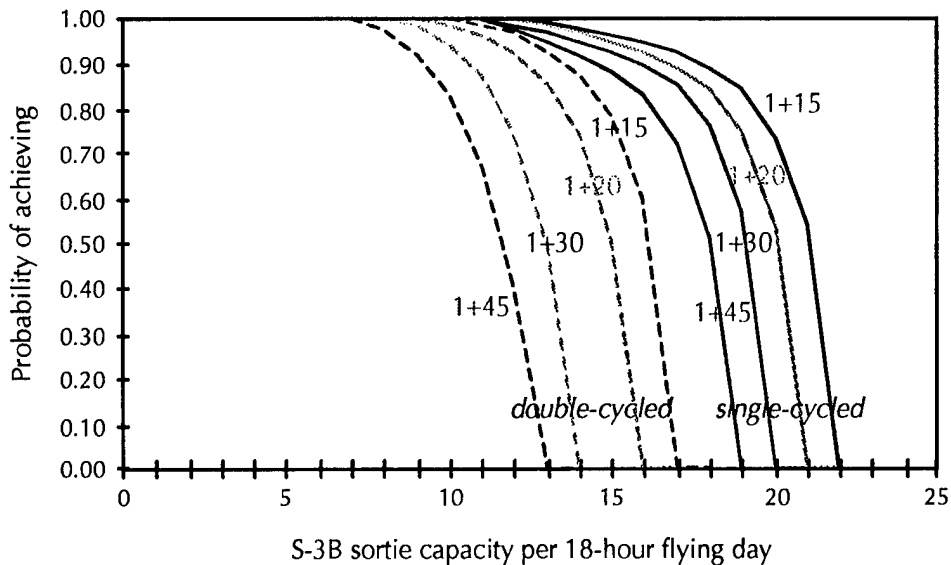
NOTE: 3 of 4 E-2Cs MC at the beginning of flight operations.

Figure 10. S-3B airframe capacity for the conduct of tanker missions



NOTE: 6 of 8 S-3Bs MC at the beginning of flight operations.

Figure 11. S-3B airframe capacity for the conduct of ASW or SSC missions



NOTE: 6 of 8 S-3Bs MC at the beginning of flight operations.

As expected, the shorter the cycle time, the greater the sortie-generation capacity of the airframes. In the extreme, if aircraft could be launched and recovered at any time (a cycle time of zero), sortie-generation estimates would be representative of operations on a well-established, large land-based airfield. Operating on the flight deck of a carrier is constrained by many factors not present for land-based operations. Indeed, during the 1997 *Nimitz* Surge, cycles of 1+00 were tried, but were found to be too stressing to the flight deck turnaround process and actually inhibited the sortie-generation process as a whole.

Sortie generation by double-cycled aircraft is significantly less than for their single-cycled counterparts. As a rule of thumb, the number of sorties possible for aircraft that are double-cycled is between two-thirds and three-fourths that of when they are single-cycled. This reflects the relative numbers of flight opportunities each cycle multiple presents to aircraft.

The number of flight opportunities of an aircraft is different than the number of carrier launches. Because aircraft recover on board the carrier after a launch, the number of flight opportunities for each aircraft (other than yo-yo tankers) is at most about half the number of carrier launches. Whenever aircraft are double-cycled, the number of flight opportunities is reduced further. For example, an aircraft that is single-cycled over 1+30 cycles has 6 opportunities to launch in an 18-hour flying day. An aircraft that is double-cycled over 1+30 cycles has 4 opportunities to launch. Table 17 shows the number of launches in an 18-hour period for air plans consisting solely of cycles of the indicated duration. The shorter the cycle time and the lower the multiple, the greater the number of flight opportunities for an aircraft and the greater potential for sortie generation.

Table 17. Airframe flight opportunities during an 18-hour flying day

Cycle time / cycle multiple	Number of carrier cycles	Number of flight opportunities
1 + 15 / single	14	7
1 + 15 / double	14	4 - 5
1 + 20 / single	13	6 - 7
1 + 20 / double	13	4 - 5
1 + 30 / single	12	6
1 + 30 / double	12	4
1 + 45 / single	10	5
1 + 45 / double	10	3 - 4

The sortie rate for a type of aircraft⁹ has historically been used as the measure of warfighting capability [7]. Typically, a single number is provided for each aircraft type which is intended to capture expected performance in all possible real-world situations. Operationally, the sortie rate will be less than the number of flight opportunities. Table 17 highlights just one shortcoming of using this measure—the execution of the mission of the carrier battle group may call for an air plan that limits the sortie rate of the aircraft, independent of the aircraft

9. The sortie rate is the average number of sorties expected each day from each aircraft on board.

itself. We know from fleet data an F/A-18C squadron can average more than 4 sorties per day per aircraft with some aircraft flying as many as 7 sorties a day—a capability that cannot be realized under a 1+45 air plan. An accurate measure of airframe capacity must encompass the variety of operational situations a carrier battle group may encounter.

Adapting airframe capacity estimates to other air plans

The estimates provided here are a product of computer modelling applied to specific air plans. The following two examples illustrate ways to adapt the estimates of airframe capacity to other air plans without having to run the computer models.

*Example 1: What is the average sortie-generation capacity (over a 19.5-hour period) of three F/A-18 squadrons, each with 9 MC F/A-18s, when the air plan uses a 1+15, 1+15, 1+45 cycle template and approximately 10 percent of the F/A-18 sorties are double-cycled?*¹⁰

To estimate the average capacity of the 27 MC F/A-18s to generate sorties in a single 19.5-hour period:

- Find the number of cycles in the 19.5-hour flight day spent at each cycle length. In this case there are ten 1+15 cycles and five 1+45 cycles. Find in table 17 the number of cycles in the base case that corresponds to each cycle time. There are fourteen 1+15 cycles and ten 1+45 cycles in the base case's flight day. The relative proportion of the flight day spent in 1+15 cycles is 0.71 ($= 10 / 14$) and in 1+45 cycles is 0.5 ($= 5 / 10$).
- Using figure 7 (at the 50 percent probability of achieving) or table 16, find the base case's estimates for the number of sorties that can be generated. The estimates are: 129 ($= 43 \times 3$) sorties for single 1+15 cycles, 105 ($= 35 \times 3$) sorties for single 1+45 cycles, 93 ($= 31 \times 3$) sorties for double 1+15 cycles, and 72 ($= 24 \times 3$) sorties for double 1+45 cycles.

10. This example is based loosely on the air plan used during the 1997 *Nimitz* Surge.

- Multiply the relative proportion of the flight day at each cycle length with the base case's estimate for the numbers of sorties to get 92 ($= 0.71 \times 129$) plus 52 ($= 0.5 \times 105$) sorties generated by single-cycled aircraft and 66 ($= 0.71 \times 93$) plus 36 ($= 0.5 \times 72$) sorties generated by double-cycled aircraft.
- Finally, multiply by the proportion of the sorties to be single-cycled and double-cycled to get:

$$(0.9 \times (92 + 52)) + (0.1 \times (66 + 36)) = 140 \text{ sorties.}$$

Example 2: What is the average sortie-generation capacity if in the previous example each F/A-18 squadron had 10 MCF/A-18s at the beginning of flight operations (instead of 9)?

- Calculate the estimated number of sorties using the base case number of MC aircraft. This was done in the previous example; we arrived at an estimate of 140 sorties.
- Find the proportion of the increase/decrease in the number of MC aircraft. In this example, it is 1.11 ($= 10 / 9$). Multiply this proportion by the number of sorties to get 155 ($= 1.11 \times 140$) sorties.

When might the airframe capacity be less?

Fewer MC airframes available

If the resources available to the carrier and air wing are less than in the base case, the sortie capacity of the airframes will suffer. The degradation to capacity in many cases will be proportional to the reduction in resources. For example, if the number of F/A-18s on board were cut to 24 and the CNO goals for MC rates were still met, we would expect the average sortie capacity to be reduced by a factor of two-thirds ($= 24 / 36$). Also, as the number of a specific aircraft type on board decreases, the variance, or range in the expected sortie-generation performance, will increase.

Many factors can cause the MC status of the air wing to be lower than our assumptions. For example, the period of high-intensity flight operations may be preceded by a period of escalating tensions in which the

air wing must operate at a relatively high tempo. Such earlier activity may reduce the MC status of aircraft below the CNO readiness goals and lower airframe sortie capacity. Also, in some operational situations, the maintenance personnel may be overtasked and not always able to cannibalize aircraft for needed parts, again decreasing the overall aircraft MC rate.

Deck-edge elevators not used during flight operations

Not using the deck-edge elevators during high-intensity flight operations has been shown to reduce sortie generation between 15 and 30 percent [8]. Further discussion of the issues related to use of the deck-edge elevators can be found in the *Flight deck capacity* section and in the appendix [1] (published separately). Many of the arguments against using the elevators during flight operations center on the difficulty of their use when the flight deck is congested. During high-intensity flight operations when many aircraft are airborne, however, the flight deck density is relatively low.

Shorter operating day

Changes in the operating environment may also reduce the sortie-generation capacity—for example, when flight operations are conducted for less than 18 hours. (An example of how to estimate the sortie capacity for flight days of different durations was given earlier.)

Non-uniform operating tempo

If the tactical situation requires varying the operating tempo significantly throughout the flight day, the sortie-generation capacity of the airframes will not be optimized. This is the case when the carrier and air wing execute α -strikes, such as those performed by the carriers operating in the Red Sea during Operation Desert Storm.

Accidents or combat damage occur

The data we used to estimate the rate at which aircraft become non-mission capable (NMC) were based on failure rates of avionics. Our estimates do not include the consequences of accidents or combat. The occurrence of either will lower the airframe capacity. It is difficult

to estimate how large a factor accidents will be. On the one hand, the deck loading decreases as the operating tempo increases, so intuitively the chance of an accident is lowered. On the other hand, increased fatigue and unfamiliarity with high operating tempos may increase human error, resulting in a higher accident rate. The frequency of combat damage depends on the capabilities of the threat and the effectiveness of our countermeasures and tactics.

Flight operations interrupted or degraded due to conduct of preventative maintenance and servicing

We assumed that all PMS on aircraft and ship aviation systems could be postponed or performed between recovery and launch of aircraft. This is not always the case. Operation Desert Storm provides such an example of how flight operations are disrupted when PMS is conducted—during the middle of offensive operations against Iraq, flight operations on USS *Midway* were ceased for 6 days while the flight deck was resurfaced.

Even when performing PMS is feasible during flight operations, it is certainly easier and faster when the flight deck is secured. PMS can always be waived, but the optimum situation is when PMS is completed on all aviation systems during the period preceding high-intensity flight operations. The problem is how to time the conduct of PMS to achieve this. If the situation permits, PMS could be performed during a short operational pause conducted immediately before the onset of high-intensity operations. Another way to keep aircraft and ship aviation systems current is to adopt a proactive policy toward PMS—conduct PMS well in advance of deadlines. If successful, such actions can significantly increase the number of MC aircraft at the beginning of an operation and enhance the firepower potential of the carrier and air wing. The cost for keeping aviation systems current is the conduct of more maintenance checks than is

technically required, which may draw down reserves of servicing supplies and increase the fatigue of aviation maintenance and flight deck personnel.

Insufficient tanker support

The ability of the U.S. Navy aircraft to operate independently of tanking depends upon their mission and employment—for the F/A-18C the duration of strike missions must be compatible with 1+20, single-cycle operations.¹¹ This equates to about a 225-n.mi. operational range.¹² The F-14s are free from reliance on tanking when the duration of strike missions are compatible with 1+15, double-cycle operations. As flight times increase, other aircraft in the air wing also require refueling. The longer the flight time, the more fuel is required.

When non-organic tankers are available, aerial refuelling should not significantly restrict the numbers of sorties generated. The carrier battle group, however, may be tasked to provide high-value airborne asset (HVAA) protection for the tankers. Indeed, U.S. Air Force policy requires such fighter cover for their tanker aircraft during real world operations. In some cases, HVAA protection may be performed by an Aegis cruiser. In other cases, some air wing fighter aircraft may need to be dedicated to the HVAA mission.

11. In a few exhibitions, the F/A-18 has demonstrated greater un-refueled ranges and longer times airborne than what we estimate. In these cases, the F/A-18s flew optimum fuel consumption profiles; deviating from these profiles will significantly increase fuel expenditure. Details on our computation of the fuel requirements can be found in [9].

12. The operational range is the distance from the carrier over which aircraft can strike targets. We based this computation on the aircraft time of flight and on the requirement for aircraft to be in the marshal pattern at the beginning of the recovery. If tanking is required, we assumed it was completed en route. We estimated the time for strike aircraft to locate the target and set up the attack as ten minutes [10]. We included a requirement for aircraft to return-to-force on a 75-n.mi. dogleg (such a requirement was imposed during Operation Desert Storm).

When non-organic tankers are not available, the air wing must rely on its own resources—the S-3B. Dedicating air wing S-3Bs to provide tanking support to F-14, F/A-18C, and EA-6B operations can extend their power-projection range. The difficulty lies in the limited fuel give of the S-3B—less than 9,600 pounds during a 1+15 sortie. Further, with longer cycle times, the S-3B requires more of the fuel it carries for its own use and thus is able to provide less fuel to other aircraft.

The sortie-generation capacity of S-3Bs can be increased by employing some of them as yo-yo tankers.¹³ During the 1997 *Nimitz* Surge, almost all S-3B sorties were tanker missions, of which about one-quarter were yo-yo tankers. We adopted this as our template for use of the S-3B as a tanker.

Table 18 and figure 12 together show our estimate of the number of strike/fighter sorties the S-3Bs can support. These calculation assume that all S-3B sorties are dedicated to the tanker mission. If only a portion of the S-3B sorties can be dedicated to refueling other aircraft, the sortie-generation capacity of the air wing is reduced from that which is shown in table 18 and figure 12.

Table 18. Number of strike/fighter sorties supportable by dedicating all air wing S-3s to tanker missions (mission time under 2 hours)

Aircraft type	Single-cycle operations with a cycle time of:		Double-cycle operations with a cycle time of:
	1+30	1+45	1+00
F-14	TNR ^a	TNR	TNR
F/A-18	240	187	108

a. TNR = tanking not required.

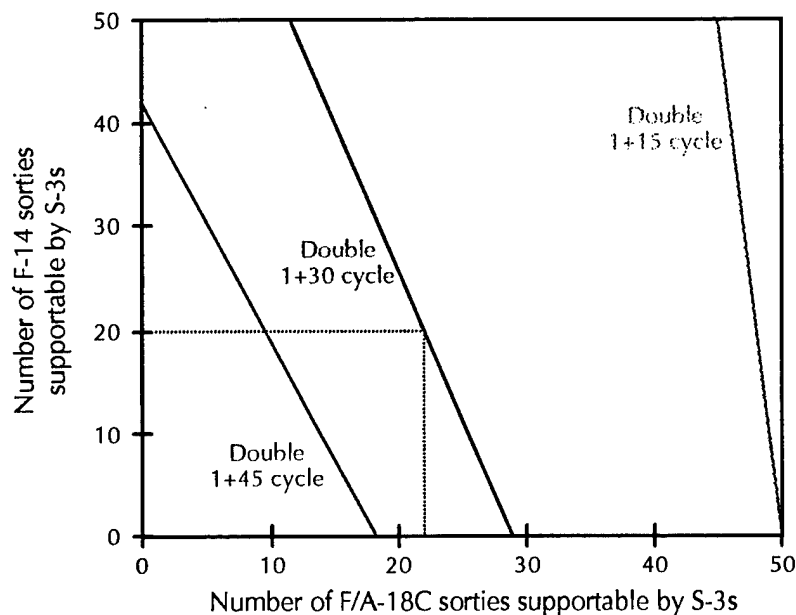
NOTE: See discussion in the *Airframe capacity* section of this memorandum and the appendix [1] (published separately) for further details on the tanking requirement and the ability of the S-3B to meet the tanking demand.

Example of use: *How many S-3B tanker sorties are required to support 20 F-14 and 75 F/A-18 strike missions when the strike/fighters are single-cycled over 1+30 cycles?*

Answer: In this situation, F-14s do not require tanking; only the F/A-18s will need S-3s dedicated to support their missions. From table 16, the capacity of S-3s to generate tanker sorties is 22. These 22 S-3B sorties can support up to 240 F/A-18 sorties (table 18). The number of S-3 sorties required to support the 75 F/A-18 sorties is 7 ($= 22 \times (75 / 240)$).

13. Yo-yo tankers launch and recover on the same cycle.

Figure 12. Number of strike/fighter sorties supportable by dedicating all air wing S-3s to tanker missions (mission time over 2 hours)



NOTE: See the discussion supporting figure 12 in the *Airframe capacity* section of this memorandum and the appendix [1] (published separately) for further details on the tanking requirement and the ability of the S-3B to meet the tanking demand.

Example of use: All strike/fighters are double-cycled over 1+30 cycles and a minimum of 20 F-14 sorties must be generated. How many F/A-18 sorties can be supported by dedicating all air wing S-3s to tanker missions?

Answer: 22 F/A-18 sorties.

We found S-3Bs can support 1+00, double-cycle operations in the base case with no degradation to F-14 or F/A-18C sortie-generation capacity.¹⁴ This equates to an operational power-projection range of about 375 n.mi. from the carrier.¹⁵

14. The F-14 does not require tanking in these cases (table 18). The F/A-18 sortie capacity of the air wing is found by multiplying the entries in table 16 for each F/A-18 squadron by 3 (the number of F/A-18 squadrons). These numbers of F/A-18 sorties are less than the number the S-3B can support (table 18).

For mission durations beyond that of 1+00, double-cycle operations, the demand from the air wing can exceed the capacity of the S-3Bs to fill. Only a portion of the F-14 and F/A-18C sorties that the carrier and air wing has the potential to generate can be supported (figure 12).

The operational cost of tasking S-3Bs to perform tanking missions may be their conduct of other missions such as ASW, SSC, and electronic warfare. This cost, however, may be less than what is initially apparent. The number of systems that the S-3 mission essential subsystems list (MESL) requires for the execution of tanking missions is relatively limited. As a result, S-3s that may not be MC for the conduct of other missions may be usable as tankers. While awaiting parts, the use of such S-3s for tanking missions does not degrade the execution of other missions. When parts are available, using S-3s as tankers would only delay their resumption of other missions as maintenance crews need wait the S-3's return to the carrier to repair their inoperable systems.

Insufficient electronic warfare support

Some aircraft missions may require the inclusion of specialized aircraft, such as the EA-6B. These aircraft are typically in short supply. In situations where an EA-6B is a critical component of a strike package, the EA-6B sortie-generation capacity may limit the number of strike packages flown. In joint operations, EA-6B support may be requested by the U.S. Air Force, which may further dilute the EA-6B support to carrier operations.

One way to "share" EA-6B assets in a low-threat environment was explored by Carrier Air Wing Nine during the 1997 *Nimitz* Surge. In that scenario, the USS *Nimitz* battle group was tasked to support littoral forces ashore and battle space superiority had been obtained. EA-6Bs continuously manned stations near the objective area, ready to support strike packages should threat indications be detected. In

15. We accounted for the time required to engage, receive fuel, and disengage from tankers when refueling was necessary in this calculation.

this exercise, the EA-6Bs were able to respond quickly to emergent requests for support from the strike/fighter aircraft.

Extended duration of operations

For operations lasting more than 7 days, sortie generation will degrade as MC rates fall with usage, spare parts and consumables are depleted, and PMS on aircraft and ship aviation systems cannot be postponed.

How can airframe capacity be increased?

Significant gains in the capacity of the airframes can be achieved by modifying the ways in which onboard resources are used. Primary among these are to extend flight operations to 24 hours a day, lower the anticipated sortie-completion rate to 85 percent, and pool the aircraft and maintenance assets of the three F/A-18 squadrons. If feasible, augmenting the squadron maintenance personnel and preemptively requesting spare parts can also increase airframe capacity. Table 19 shows our estimates of the potential increases in airframe capacity resulting from these measures. These are average values; in a real world operation, performance will vary somewhat about these expected values.

We illustrate the increased capacity possible from these measures in figures 13 and 14. Both figures pertain to the F/A-18 and show what is possible during 1+15 and 1+45 single-cycle operations. The bars in these figures span the 10 to 90 percent confidence bounds around our estimates. Two conclusions are evident from the figures and table:

- The value-added of these measures decreases with increased flight time.
- While the number of sorties possible from the S-3 is also increased by these measures, it is frequently not sufficient to meet the increased tanking demand from the strike/fighters. For example, during 1+15, double-cycle operations the S-3s can support up to 50 F/A-18 sorties, while the F/A-18 airframes are capable of generating 93 sorties. To realize the full potential of

the F/A-18 and the gains from (1) accepting a sortie-completion rate (SCR) of 85 percent, (2) pooling F/A-18 squadrons, or (3) augmenting maintenance personnel, non-organic tankers must be available.

As a last resort, augmenting the number of aircraft on board (provided there are aircrew to fly them, maintenance personnel to repair them, and flight deck crews to ready them for launch) may increase the firepower capacity of the carrier battle group.

Table 19. Potential gains in the capacity of airframes (each squadron)

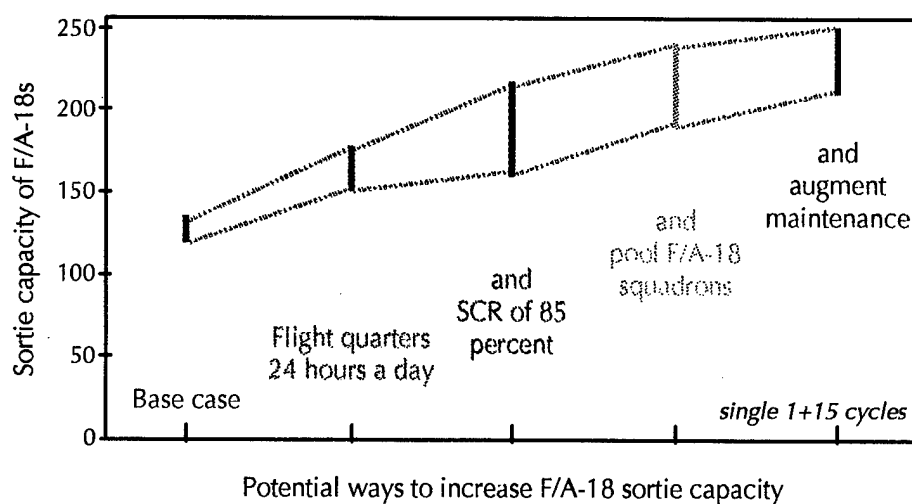
	Base case	... and flight quarters 24 hours a day	... and SCR of 85 percent	... and pool F/A-18 squadrons	... and augment maintenance / aggressive logistics policy
F-14:					
1+15, single-cycle	27	32	39	n/a	46
1+20, single-cycle	26	32	38	n/a	45
1+30, single-cycle	25	31	36	n/a	43
1+45, single-cycle	23	29	33	n/a	39
1+15, double-cycle	21	27	32	n/a	36
1+20, double-cycle	20	25	31	n/a	34
1+30, double-cycle	19	25	29	n/a	31
1+45, double-cycle	17	23	26	n/a	29
F/A-18C^a:					
1+15, single-cycle	43	56	64	72	80
1+20, single-cycle	42	54	62	70	77
1+30, single-cycle	39	50	57	63	68
1+45, single-cycle	35	45	52	57	60
1+15, double-cycle	31	40	48	53	56
1+20, double-cycle	29	38	45	49	51
1+30, double-cycle	27	35	42	46	49
1+45, double-cycle	24	32	37	40	42
EA-6B:					
1+15, single-cycle	13	15	20	n/a	22
1+20, single-cycle	13	14	19	n/a	21
1+30, single-cycle	13	14	18	n/a	20
1+45, single-cycle	11	14	17	n/a	19
1+15, double-cycle	10	13	16	n/a	17
1+20, double-cycle	9	12	15	n/a	16
1+30, double-cycle	8	10	14	n/a	15
1+45, double-cycle	8	10	12	n/a	13
E-2C:					
1+45, double-cycle	8	10	11	n/a	11
1+15, triple-cycle	8	10	11	n/a	11
1+20, triple-cycle	8	10	11	n/a	11
1+30, triple-cycle	7	9	10	n/a	10
S-3B^b:					
1+15, single-cycle	24 / 20	30 / 26	36 / 32	n/a	36 / 33
1+20, single-cycle	23 / 20	29 / 25	35 / 30	n/a	35 / 32
1+30, single-cycle	22 / 19	27 / 23	33 / 28	n/a	33 / 30
1+45, single-cycle	20 / 17	26 / 22	30 / 25	n/a	30 / 27
1+15, double-cycle	- / 15	- / 20	- / 23	n/a	- / 24
1+20, double-cycle	- / 15	- / 20	- / 23	n/a	- / 24
1+30, double-cycle	- / 13	- / 18	- / 20	n/a	- / 21
1+45, double-cycle	- / 11	- / 15	- / 18	n/a	- / 19

a. Each squadron.

b. Tanker mission (25 percent yo-yo tankers and 75 percent mission/recovery tankers) / (ASW or SSC) missions.

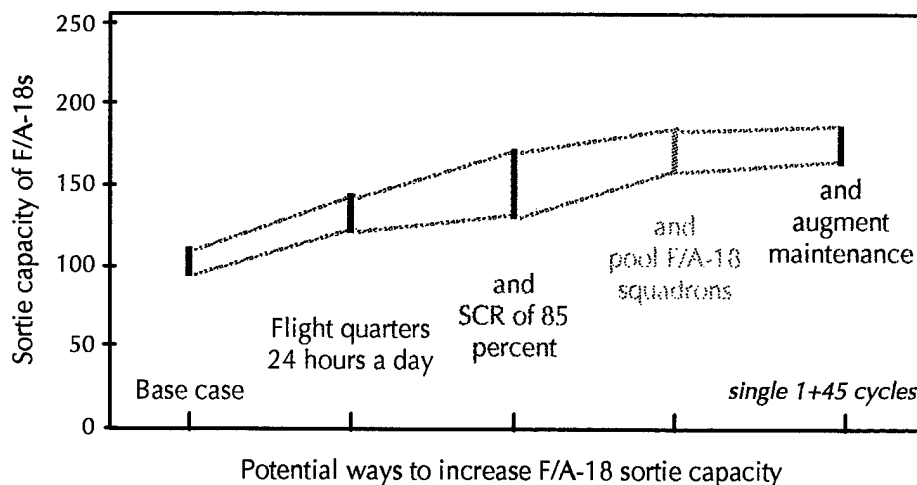
NOTE: Gains for each measure are additive. For example, the capacity realized from accepting an SCR of 85 percent assumes the flight deck is operated 24 hours a day.

Figure 13. Potential gains in F/A-18 sortie capacity during 1+15, single-cycle operations



NOTE: (1) Gains for each measure are additive. For example, the capacity realized from accepting an SCR of 85 percent assumes the flight deck is operated 24 hours a day.
 (2) Tanking not required.

Figure 14. Potential gains in F/A-18 sortie capacity during 1+45, single-cycle operations



NOTE: (1) Gains for each measure are additive. For example, the capacity realized from accepting an SCR of 85 percent assumes the flight deck is operated 24 hours a day.
 (2) Tanking required.

Conduct flight operations 24 hours a day

Continuous flight operations should increase the sortie-generation capacity of the airframes by almost one-third over that of 18-hour flight operations. However, before the 1997 *Nimitz* Surge, carriers rarely operated at a high operating tempo more than 18 hours a day. The presumption was that some standdown time was needed to exchange NMC aircraft on the flight deck with MC aircraft trapped in the hangar bay; conduct replenishment; give flight deck crews, air operations personnel, and aircrews time to rest; perform PMS on ship and aviation systems; conduct FOD walkdowns; and perform other carrier and air wing housekeeping activities. What USS *Nimitz* demonstrated in 1997 was that operations on the flight deck were actually *easier* when flight operations were not paused; all of the activities previously reserved for non-flying hours, with the exception of replenishment,¹⁶ could be conducted during flight quarters. By not having to periodically recover all aircraft, the flight deck was not congested and turnaround operations eased.

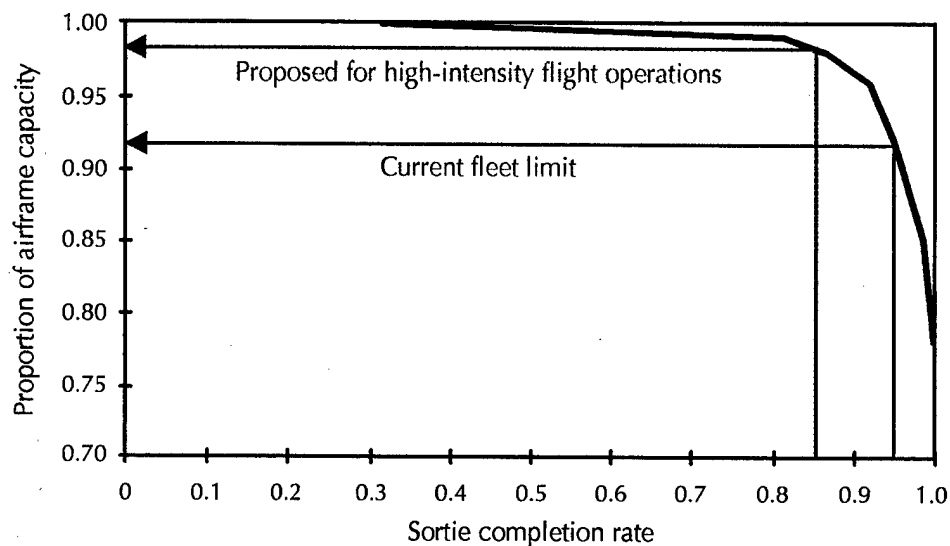
Permit sortie-completion rates as low as 85 percent

The percentage of sorties that are scheduled and do fly is the SCR. Current fleet practice is to design air plans so as to achieve a 95 percent or higher SCR. A high SCR rate is insurance that the overall operation will go essentially as planned. However, this insurance does have a cost—the capacity of the airframes is not fully tapped. If a sortie is not scheduled, it does not fly. In the extreme, scheduling only a handful of sorties will result in an SCR of 100 percent, but still only a handful of sorties is generated. In contrast, if a more aggressive schedule was written—for example scheduling 225 sorties in a 24-hour flying day—our simulation models indicate 36 F/A-18s (with

16. A new replenishment concept, Just In Time Ordnance Delivery (JITOD), may allow replenishment of ordnance concurrent with flight operations and is being developed and tested in the fleet. Implementation of JITOD currently requires frequently respotting the hangar bay, which increases the workload of aircraft directors and handlers. If JITOD can be implemented successfully and efficiently, this would increase the time a carrier and its embarked air wing can conduct power projection before pausing to replenish.

27 of them MC) could generate almost 200 sorties for an SCR of 85 percent. By demanding an SCR of 95 percent, the sortie-generation potential of strike/fighters is reduced by about 15 percent (figure 15). By accepting air plans with an expected SCR of 85 percent, more sorties would be generated and virtually all of the sortie capacity resident in the F/A-18s might be achieved.

Figure 15. SCR limit to airframe capacity



There is a cost to accepting air plans with a lower SCR—flight deck operations may need to be more responsive to aircraft unavailability. This might require the missions tasked on each cycle be prioritized, with the anticipation that the lower priority missions might not be flown. Aircraft assigned to higher priority missions would be readied first and aircrews would be assigned to specific airframes shortly before pre-flight inspection of the aircraft.

Pool F/A-18 resources

The F/A-18s in the air wing are normally operated in three squadrons. Each squadron has its own command structure, pilots,

maintenance personnel, and ordnance-loading crews. This eases training during peace time, but because aircraft availability is not always uniform across the three F/A-18 squadrons, it does limit the airframe capacity during high-intensity flight operations.

When firepower is at a premium, sortie generation can be increased by between 8 and 13 percent if the F/A-18 squadrons are treated as a pooled asset—a single source of aircraft, pilots, and ordnance and maintenance personnel for meeting the scheduled requirements. Pooling the F/A-18 squadrons has the added benefit of easing the readying of aircraft for flight and reducing the number of deck-edge elevator runs required (see the *Flight deck capacity* section of this memorandum).

The three F/A-18 squadrons were pooled during the 1997 *Nimitz* Surge. Pilots from one F/A-18 squadron flew aircraft provided by any of the three F/A-18 squadrons. A “super team” of maintenance personnel from the three squadrons was formed, which resulted in an overall increase in F/A-18 MC rate and sortie generation.

To implement F/A-18 pooling procedures, protocols must be established. For example, responsibility for the maintenance, parts, fuel, and turnaround of the shared aircraft have to be clearly articulated. Protocols should address the conditions under which the aircraft would return to its original squadron and whether or not the aircraft was a candidate for cannibalization. These protocols need to be in place and agreed upon by all parties well in advance of implementation.

Super spare strike/fighters

With the *Super Spare* concept, a spare need not be drawn from the same strike/fighter squadron as the NMC strike/fighter. For example, an F-14 could spare for another F-14 or for an F/A-18, provided the mission was the same. In essence, Super Sparing aircraft is a means of pooling assets between strike/fighter squadrons. As with conventional spares, the pilot of the Super Spare attends mission briefings and the strike/fighter is loaded with weapons appropriate for the mission.

The nature of strike operations during high-intensity operations frequently lends itself to use of the Super Spare concept. The consolidation of strike tactics by the Naval Air and Strike Warfare Center (NSAWC) allows aircrews from different squadrons, indeed different air wings, to be current in the same tactical procedures. In many operational situations calling for high-intensity flight operations, the load plan should not vary significantly from one launch to the next. In these cases, unused Super Spare aircraft do not have to be reconfigured from one launch to the next. This eases the demands on the ordnance crews. Indeed, ready aircraft intended for launch on later events could be used to Super Spare the current event.

Sparing comes with costs. Pilot utilization rates increase and aircraft must undergo servicing (although not as extensive a procedure as is required after a flight), which increases the workload of maintenance crews.

Preemptively request spare parts and servicing expendables in anticipation of need

NMC aircraft are either awaiting spare parts (NMCS) or awaiting maintenance (NMCM). An aircraft can be designated NMCS if the parts are in ship's supply or must be brought from the depot. A high NMCS rate means either the required spare parts were difficult to break out from the parts storage lockers or that the logistics support was not responsive to the air wing's needs.

We used AV3M data from NAVICP covering carrier deployments during January 1996 through June 1997. Most of these data were taken during periods of low-intensity peacetime operations and are an amalgam of high-priority and low-priority parts requests. We also used data collected during the high-intensity flight operations of the 1997 *Nimitz* Surge. However, because the *Nimitz* Surge was conducted off the southern California coast, the logistics response time was artificially low. (Typically, requests for spare parts were filled within 12 hours.) Thus, the data we show in table 20 should bound that expected during real world high-intensity flight operations. We used the standard Subsystem Capability Impact Reporting (SCIR) formula to calculate the AV3M readiness rates (table 20). Table 20 shows (and

figure 16 graphs) the different experiences of the three F/A-18 squadrons during the USS *Nimitz* Surge—while two squadrons were significantly below the fleet average for NMCS, the third was considerably above. This type of variation occurs frequently during operations of short duration.

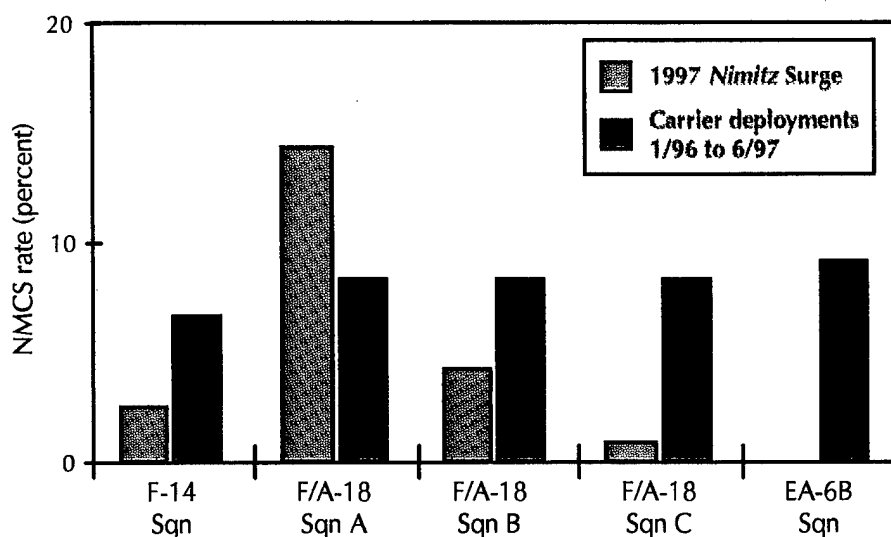
Table 20. NMCS and NMCM rates (AV3M data) for carrier deployments 1/96 to 6/97 and the 1997 *Nimitz* Surge

Type aircraft	Percent of deployed U.S. Navy aircraft 1/96 to 6/97				Percent of aircraft observed during 1997 <i>Nimitz</i> Surge			
	NMCS	NMCM— in work	NMCM— awaiting maintainer / respot	MC	NMCS	NMCM— in work	NMCM— awaiting maintainer / respot	MC
F-14A	6	10	14	70	3	8	34	55
F/A-18C	8	4	10	78	6	5	8	81
(composite)								
Squadron A	DNA ^a	DNA	DNA	DNA	14	4	6	77
Squadron B	DNA	DNA	DNA	DNA	4	5	9	82
Squadron C	DNA	DNA	DNA	DNA	1	5	10	84
EA-6B	9	3	10	78	0	3	2	95
E-2C	8	3	8	81	4	3	8	85
S-3B	15	4	11	70	9	3	9	79

a. DNA = data not available.

The importance of logistics in short duration operations will be dependent on the warning time available and the proactive, vice reactive, actions of the carrier Supply Officer and the air wing Maintenance Officer. Although requesting parts that may be needed for the operation can significantly increase the readiness and sustainability of the carrier and the air wing, it does stress the logistics system. The data indicate that if the NMCS rates could be lowered (and there were sufficient maintenance personnel to install the parts in the aircraft in a timely manner), the sortie capacity of the airframes could increase by as much as 10 to 20 percent. Roughly half of this increase would be attributable to lowering the logistics response time and the other half to reducing the shipboard logistics response time (LRT).

Figure 16. NMCS rates for carrier deployments 1/96 to 6/97 and the 1997 *Nimitz* Surge



Increase O-level aviation maintenance manning

An aircraft is NMCM if (1) no maintenance personnel are available to repair it, (2) it must be respotted before work can begin, or (3) it is currently in work. A large time spent in NMCM status suggests one or more of the following:

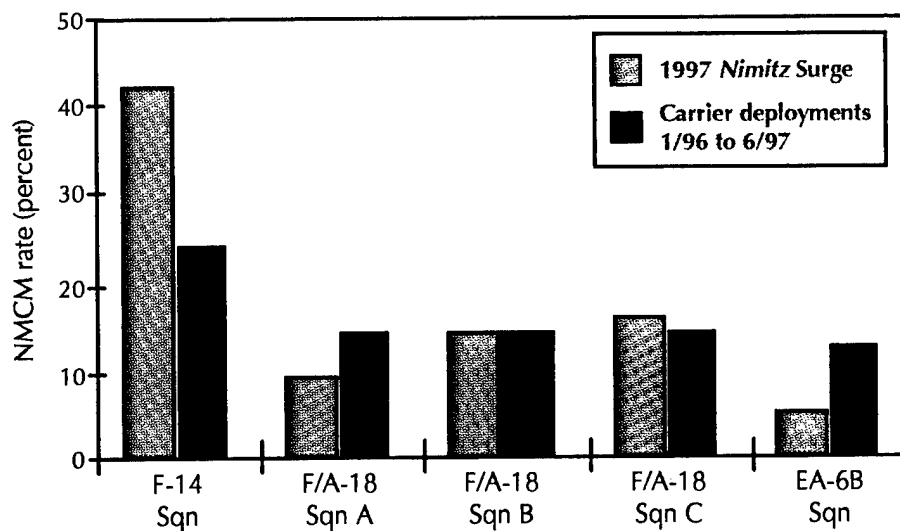
- The number of squadron maintenance personnel to service the aircraft was insufficient.
- Aircraft were not spotted in locations that allowed maintenance actions.
- A large number of aircraft underwent maintenance.

As before, we used AV3M data from NAVICP covering carrier deployments from January 1996 through June 1997 and the 1997 *Nimitz* Surge. Based on the maintenance manning levels of deployed carriers and air wings, between 8 and 14 percent of the fixed-wing aircraft on board were unavailable for tasking because insufficient numbers of personnel were available to work on them or the aircraft were awaiting a respot.

Increasing the number of qualified maintenance personnel on board can improve the timeliness of the O-level repair of aircraft. The first step in the maintenance process is determining the aircraft's problem. This maintenance triage function is performed by the "troubleshooters," the select few of the senior, experienced maintenance personnel. During the 1997 *Nimitz* Surge, the troubleshooters proved their worth, but were over-tasked. As a result, a recommendation of the *Nimitz* Surge assessment [3] was to augment each strike/fighter squadron with 2 to 4 experienced troubleshooters.

Once diagnosed, augmenting each squadron with additional maintenance personnel will reduce the time aircraft await repair. Based on operational data on NMCM rates (figure 17 and table 20), we estimate the number of additional O-level maintenance personnel required to support high-intensity operations for the F-14 squadron could be as high as 29 percent over BA and for the other aviation squadrons as high as 13 to 18 percent over BA.

Figure 17. NMCM rates for carrier deployments 1/96 to 6/97 and the 1997 *Nimitz* Surge



Because some part of the time spent in NMCM status is spent awaiting a respot, the number of personnel and the potential increase in sortie generation shown in table 21 overestimates the requirement and potential gain. We do not have data on the relative contribution of each of these two factors to the NMC rate, so we cannot directly estimate the required number of additional maintenance personnel needed to achieve the potential increase in sortie generation.

Table 21. Size of required O-level maintenance augmentation

Type of aircraft	Number of aircraft on board	Maximum increase in maintenance personnel (percent)	Maximum increase in sortie generation (percent)
F-14A	10	29	20
F/A-18C	36	16	13
EA-6B	4	14	13
E-2	4	13	10
S-3B	8	18	16

The carrier's aviation intermediate maintenance department (AIMD) likely does not need augmentation, as AIMD will probably be relegated to expeditious repair during short duration, high-intensity operations. However, AIMD's backlog of work may climb precipitously and the ability of AIMD personnel to support follow-on operations may be affected unless they, too, are augmented with additional personnel.

Aircraft augmentation

CNO has raised the possibility of augmenting deployed air wings in times of crisis with additional aircraft. In most operational situations, the availability of strike/fighter airframe is not the limiting factor to sortie generation. Under certain circumstances, S-3 and EA-6B airframe availability may limit the firepower potential of the carrier and air wing. If airframe capacity is determined to be the limiting factor, additional aircraft might ease that limitation. Further, additional aircraft can serve as on-site attrition fillers for aircraft lost to combat or accidents.

The size of the augmentation is constrained by the amount of space on the carrier; the space available is determined by the number and type of aircraft and support equipment initially on board and the level of deck loading tolerated. As the aircraft density is increased, flight and hangar deck operations become more difficult and the sortie-generation capacity of the carrier and air wing is diminished. USS *Nimitz* has a maximum spot capacity of 130 (hangar and flight decks combined). At this loading, there is no room to operate and the deck is considered "locked," so no sorties can be generated. Commander, Naval Air Forces Atlantic's guidance in the mid-1970s set operating capacities at 75 percent [11]. (Although this instruction is fairly old, we were unable to locate a more recent version.) Staff members of N8 and N3/5 suggested 80 percent as a maximum upper bound. The nominal baseline air wing configuration shown in table 13, along with general service equipment (GSE) and miscellaneous equipment, weigh in at 73 percent of USS *Nimitz* capacity. Thus, because 80 percent is the operating limit, there is room for additional aircraft on board.

The composition of the augmentation will determine the resulting deck loading. Our analysis indicates that in most operational situations, the F/A-18C (the sortie-generation workhorse of the air wing), S-3B (to increase organic tanking capacity), or the EA-6B (to increase ECM capabilities in theater) will be the most likely candidates for augmentation. Our assessment agrees with the conclusion of [12]. The size of a *Nimitz*-class carrier will limit the size of the augmentation to between 7 and 9 aircraft.

One potential difficulty in augmenting aircraft is the logistics of getting them to the carrier. Mobilization plans for major theater wars (MTW) are fully developed and altering them would require decisions at the highest levels. Because lift capacity is fully taxed, any change to give preference to naval aircraft would require delaying the arrival of other warfighting assets. Further, recent experiences in the Persian Gulf and Adriatic Sea place doubt on whether allies in those regions will allow U.S. forces the use of their airfields in times of conflict.

Another consideration is the readiness of the aircraft and aircrew upon arrival. Some operators speculate that after such a transit it might be several days before the aircrew and aircraft would be fully combat ready.

Pilot and aircrew capacity

The capacity of the pilots¹⁶ to generate sorties is based on two factors:

- The number of pilots on board available to fly.
- The limit on pilot utilization rate¹⁷ specified for the operation.

Fleet exercises have found that the number of pilots is typically the limiting factor in sortie generation during high-intensity flight operations [13]. We expect this to be true of real world operations as well—pilots are a sought after resource in scarce supply. Their insight into carrier operations makes them ideal candidates for Liaison Officer (LNO) duty and their experiences in mission execution are a valuable contribution to campaign planning. These two temporary duty assignments typically are performed off the carrier. On board the carrier, the pilots' expertise is routinely tapped in oversight of air wing operations, be it waving aircraft on board as the Landing Signals Officer (LSO), coordinating squadron functions as the Squadron Duty Officer (SDO), or standing watch in primary flight control (pri-fly), strike operations, and air operations. While performance of these other duties is valuable, every additional assignment diminishes the ability of the pilot to perform his primary duty—flying aircraft.

For our base case, we assume the number of pilots assigned to the air wing (table 13) and pre- and post-mission conduct are typical of that of current deployed carrier battle groups. Our assumptions about aircrew qualifications, aircrew availability for flight duty, required crew

16. The term "pilots" will be used synonymously with "aircrew" in the remainder of this memorandum.

17. The pilot utilization rate is the average number of times a pilot mans an aircraft per day, for whatever reason. The rate encompasses sorties flown, the times spare aircraft are manned, and the times a manned aircraft goes down before launch.

rest, and the ratio of man-ups to sorties flown are provided in the *Base case* section of this memorandum. The appropriate upper bound on the pilot utilization rate depends on the workload intrinsic to the execution of the mission and stress of combat, along with consideration of the non-flying tasking of the aircrews. Further, the amount of time spent planning and preparing for a combat sortie and completing post-mission debriefs can vary considerably. Because the bound on pilot utilization rate can vary significantly from one operational situation to the next, we estimate pilot capacity for pilot utilization rates between 1.0 and 3.0.

Capacity of pilots in the base case

Our results are shown in figure 18 and table 22. We caveat our results as follows:

- These estimates are unconstrained by the need to have aircraft readied and available for the aircrew to fly.
- The impact of combat fatigue is not incorporated.

Setting the cap on pilot utilization rate

In real world operations, the number of combat sorties an aircrew can be expected to fly is highly variable. Factors such as individual crew stamina, level of threat encountered, operating tempo, type of combat mission, time of day, and prevailing weather conditions can influence the choice of the operational commander. To gain insight into appropriate bounds for the pilot utilization rate, we summarize what U.S. Navy and U.S. Air Force doctrines tell us about pilot utilization rates, combine this with data from recent real world operations, and present the constraints that time places on pilot utilization and mission completion.

Figure 18. Pilot capacity in the base case

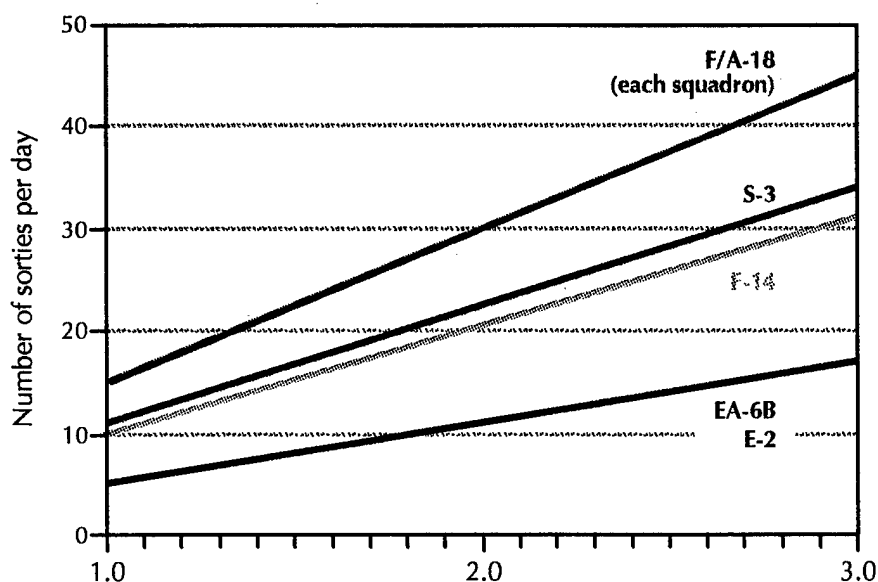


Table 22. Pilot capacity in the base case

Pilot utilization rate	Number of sorties per day				
	F-14	F/A-18 (each squadron)	EA-6B	E-2	S-3
1.00	10	15	5	5	11
1.25	13	19	7	7	14
1.50	15	22	8	8	17
1.75	18	26	9	9	19
2.00	20	30	11	11	22
2.25	23	34	12	12	25
2.50	26	38	14	14	28
2.75	28	41	15	15	31
3.00	31	45	17	17	34

NOTE: Recall that in the base case collateral duties prevent some of the aircrew from flying (for example, aircrew who are TAD as LNOs off ship).

U.S. Navy and U.S. Air Force doctrine

Most of the U.S. Navy doctrine that we found deals only with F/A-18 pilot utilization. Several published official assessments of sortie rates for high-intensity, combat operations also specify aircrew manning levels, though not all are consistent with each other. Because these

assessments presumably encompass all possible constraints to sortie generation, we can derive lower bounds on the underlying pilot utilization rates (table 23) and make some inferences based on these assessments. Because N512's baseline estimate increases when only the number of pilots are increased, this indicates it is the *pilots* in their assessment, not the aircraft or the operations on the flight deck, which limit overall sortie generation. Also, N512 apparently incorporates the benefits of sharing the collateral duties among a larger number of pilots since the pilot utilization rate increases as the number of pilots increases. OPNAV Instruction 3710.7Q [17] states that "daily flight time should not normally exceed three flights or 6.5 total hours flight time for flight personnel of single-piloted aircraft," but adds the caveat that this restriction can be waived by the operational commander. If not waived, the OPNAV instruction requires sharp declines in pilot sortie rates when the missions are extended from single-cycle to double-cycle operations. Double-cycled flights are more demanding; certainly, more time is spent flying, much of which may be over enemy territory and may require more extensive planning. The OPNAV instruction does not mention the types of missions that could be flown.

Table 23. U.S. Navy pilot utilization limits (high-intensity flight operations)

Originator	Number of F/A-18 pilots on board	Number of F/A-18 aircraft on board	Pilot utilization rate	Duration
N88 [14]	83	48	1.50	3 to 4 days
N88 [14]	83	48	1.73	3 to 4 days (optimal conditions)
N512	48	36	1.50	3 to 5 days
N512	68	36	1.76	3 to 5 days
N512	80	36	1.92	3 to 5 days
Operation Desert Storm (AGBF)	Data not supplied in [15] or [16]		1.55	3 days (final ground offensive)
OPNAVINST 3710.7P	n/a	n/a	3.0 to 3.9 ^a (single-cycle operations)	7 days
OPNAVINST 3710.7P	n/a	n/a	1.7 to 2.3 ^b (double-cycle operations)	7 days

a. For cycle times: 1+15, 3.9; 1+20, 3.7; 1+30, 3.4; 1+45, 3.0.

b. For cycle times: 1+15, 2.3; 1+20, 2.1; 1+30, 1.9; 1+45, 1.7.

Operational data on pilot sortie rates in combat are limited and must be viewed within their context. For example, we must consider such questions as:

- What was the duration of the conflict?
- What was the complexity of the missions executed?
- Were the aircrews tasked to full capacity?
- Did other factors influence the number of sorties flown?

During the Vietnam conflict, pilots were allowed to fly at most two combat and one non-combat sortie each day [18].¹⁸ Table 23 includes the sortie rates flown by F/A-18 pilots operating off carriers in the Persian Gulf during the final three days of Operation Desert Storm—a period of high-intensity flight operations.

The information in [19] allows calculation of lower bounds on U. S. Air Force estimates of acceptable pilot utilization rates (table 24). For this calculation, we used their data representative of high-intensity combat operations; however, no indication of mission flight time was associated with these data. Other factors may be limiting U.S. Air Force pilot sortie rates, but the actual limits the U.S. Air Force uses in planning are at least as large as these.

Table 24. Lower bounds for U.S. Air Force pilot utilization rates

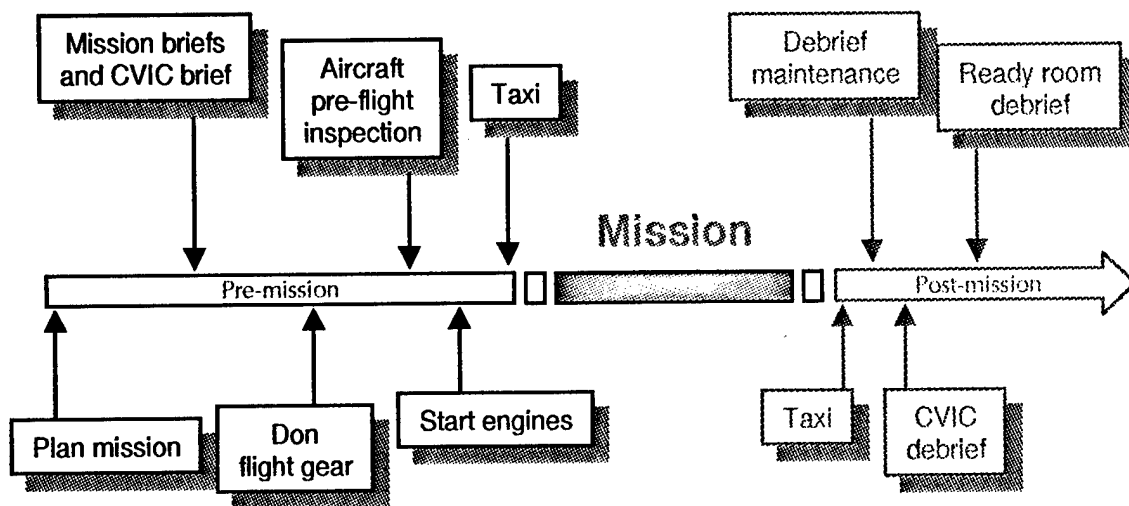
Aircraft	Minimum pilot utilization rate
F-15E	1.0
F-16	1.4
A-10	1.7
F-15C	1.2

18. Some waivers of this were granted on a case-by-case basis.

Mission overhead—preparation and debrief

In determining the bound for pilot utilization rate, a key component is the amount of time each mission requires. A mission consumes much more of a pilot's time than just what is spent in the air. Time is spent before the scheduled sortie preparing for the mission and following the sortie in debriefing. For instance, [20] recommends pilots man their aircraft 45 minutes before their scheduled launch. This allows sufficient time for aircrew to conduct a pre-flight check of the aircraft and, after the engines are started, to align the inertial navigation system of the aircraft with that of the carrier, enter mission data in the aircraft computer, and check the aircraft's electrical systems. Figure 19 depicts the typical flow of events before and after a sortie.

Figure 19. Mission overhead



The flight time ($Time_{flight}$) will vary by aircraft type and assigned mission, and will be reflected in the sortie's scheduled cycle time and cycle multiple. Our nominal air plans are composed of cycles that are exclusively 1+15, 1+20, 1+30, or 1+45 in duration. We consider only situations when aircraft are single- or double-cycled or, in the case of the E-2, triple-cycled.

Because the campaign objectives drive the master air attack plan (MAAP), which determines the carrier's air plan, the minimum flight time is typically beyond the control of the battle group commander. In contrast, the time required to prepare and debrief the mission ($Time_{prep+debrief}$) will depend on the complexity of the mission, the threat, and events occurring during the mission but is, at least to some degree, controllable.

Missions must be accomplished within a pilot's work day. Aviation physiologists recommend that aircrews' workdays be no more than 15 hours [21]. Accomplishing non-flying tasks will reduce the time for mission execution further. The relationship between pilot utilization rate (Ute_{pilot}) and the time dedicated to the mission is:

$$(Time_{prep+debrief} + Time_{flight}) \times Ute_{pilot} \leq 15 \text{ hours.}$$

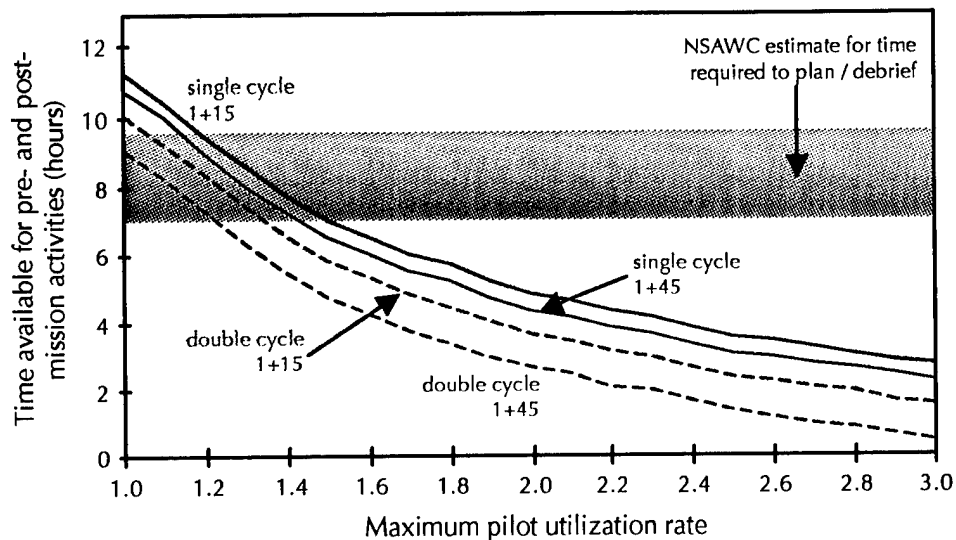
Figure 20 graphs this relationship with curves corresponding to typical flight times of single- and double-cycled missions that are flown over cycle times of 1+15 and 1+45. For example, if the firepower required to achieve mission objectives demands a pilot utilization rate of at least 2.0, the average length of time that can be spent on mission planning and debriefing is at most 4.8 hours (for single, 1+15 missions) and may be as little as 2.7 hours (for double, 1+45 missions). For triple-cycle missions, the E-2 crews have between 1.9 and 3.3 hours for mission preparation and debriefing.¹⁹

Lowering the time spent in preparing and debriefing a mission can dramatically increase the potential pilot sortie capacity. Figure 20 can be used to determine this increase. For example, if F/A-18 pilots

19. Longer flight times not only reduce the time available for planning and debriefing a mission, but may increase the time needed to return a crew to full combat readiness. In many operational situations, longer missions spend more time over enemy territory and result in a disproportionate increase in pilot fatigue. If this is the case, the time available for planning and debriefing a mission is reduced further.

require 8 hours to prepare and debrief each 1+45 single-cycled mission, the maximum pilot utilization rate that could be attained is 1.3. If preparation and debrief time can be reduced to four hours, the maximum utilization rate can be increased to 2.3—a gain of over 75 percent in firepower capacity.

Figure 20. Mission overhead, flight time, and pilot utilization rate



The calculations shown in figure 20 did not consider three factors, each of which will reduce the pilot utilization rate realizable during real world operations. First, the computation assumed a maximum packing of missions into the work day; such efficiencies are easy to achieve on paper, but almost impossible in practice. Second, this nomogram does not incorporate the stress of flying combat missions. And lastly, flying a night sortie is far more demanding than a daylight flight. In those cases where mission planning allows a pilot utilization rate over 2.0, at least one flight will be at night.

Indicated on figure 20 are NSAWC's estimates of the length of time required to plan a "nominal" interdiction strike (6 to 8 hours)²⁰ and the time typically spent in debriefing (1 to 1.5 hours). We used NSAWC's estimates to calculate the pilots' capacity to generate sorties in the base case (table 25).

Table 25. Inclusion of NSAWC's estimates for mission overhead

	Average number of man-ups				Average number of sorties			
	Single-cycle, 1+15	Single-cycle, 1+45	Double-cycle, 1+15	Double-cycle, 1+45	Single-cycle, 1+15	Single-cycle, 1+45	Double-cycle, 1+15	Double-cycle, 1+45
F-14	19	18	17	16	15	14	14	13
F/A-18 ^a	20	19	18	17	19	18	17	16
EA-6B	9	8	8	7	9	8	8	7
S-3	17	16	15	14	16	15	14	13

a. Each squadron.

NOTE: Every man-up requires 6 to 8 hours of preparation; every sortie requires 7 to 9.5 hours of preparation and debrief.

When might pilot capacity be less?

Fewer pilots available

The number of aircrews is a key factor in the number of sorties possible. If fewer pilots are available than in the base case, either from lower manning, loss of day/night carrier qualifications, greater tasking off ship, sickness, or combat loss, the sortie-generation capacity of the air wing will be proportionally less.

20. Not all missions are expected to require this much time for planning. Some missions, such as CAS, may not require extensive planning, especially after aircrew are familiar with the area of operations. In these situations, pilots can recover, launch on the next event to the same target area, and receive mission updates in the cockpit.

Administrative tasks cannot be postponed

Some administrative tasks may be pressing in their own right. For example, during Operation Desert Storm, squadron commanders had to complete yearly fitness reports on the officers under their command. To postpone this duty would have meant U.S. Navy promotion boards would meet without their inputs and their subordinates' careers could suffer. If they cannot be postponed, these tasks will diminish the capacity of the air wing pilots.

Pilot utilization rates below cap

Not all pilots will fly the maximum number of missions allowed. Counted in the number of pilots in a squadron are those in command positions, such as the squadron Commanding Officer, the Executive Officer, and the Maintenance Officer. These individuals may have significant non-flying tasking and be unable to fly as many missions as other pilots in the squadron.

The air wing and battle group commander set the bound on the number of sorties each pilot can fly. Many factors influence this choice, including the weather and sea state in the carrier operating area. Squadron commanders may limit the flying of individual pilots further, based on their assessment of the pilot's readiness for combat. In practice, the average pilot utilization rate taken over the air wing will be less than the cap set by the air wing and battle group commander. The rates shown in table 25 are an upper bound that which is possible to achieve.

Fatigue and combat stress reduce pilot utilization rate

Life on board a carrier during high-intensity combat operations is not an environment conducive to rest. The living habitat is noisy and, when coupled with the anticipation of combat, makes rest difficult to obtain. Moreover, after a combat mission the effects of adrenaline on a pilot's body cause further exhaustion. The time necessary to rejuvenate aircrew to full combat readiness after each mission may increase as the operation progresses. This may mandate a reduction in the pilot utilization rate with time.

One way to enhance performance, maintain alertness, and encourage sleep is through the use of stimulants and sedatives. The U.S. Navy does not allow the use of medications to aid sleep or promote alertness. In contrast, the U.S. Air Force has for many years allowed the use medications—stimulants to promote wakefulness and sleep inducers—to manipulate the alertness of aircrew with few, if any, negative results.

How can pilot capacity be increased?

Reduce the non-flying tasking of air wing pilots

The aircrew are unique resources to the carrier battle group and are in limited supply. They, and they alone, can fly aircraft on missions. This capability also gives them knowledge and insight into carrier operations that makes them desirable candidates for many other temporary duty assignments, such as LNOs. In some operational situations, the benefits of assigning aircrew to these other duties outweighs the loss to the firepower capacity of the carrier battle group. However, such assignments should be weighed carefully—*every F/A-18 pilot sent as an LNO reduces his squadron's pilot work force by 6 percent.*

Reducing other non-flying duties can increase the firepower capacity. For example, *consolidating pre-fly watches and LSO duties among the F/A-18 squadrons increases each F/A-18 squadron's capacity by 14 percent; delegating those duties totally to CAG staff increases each F/A-18 squadron's capacity by 20 percent.*

Reduce the time pilots spend in mission planning, preparation, and debriefing

Reducing the amount of time spent in preparing for a mission, provided the quality of the preparation is not compromised, can significantly increase the potential pilot utilization rate. This could be accomplished by using computerized planning aids or delegating some mission planning tasks to non-fliers.

Mission planning aids such as TAMPS, TOPSCENE, and the portable flight planning software (PFPS) have been available in the fleet for

many years with varied success. Provided the aids are easy to use and aviators have confidence in their products, their use can translate directly into added firepower capacity. For example, suppose planning a mission scheduled for a 1+15, single-cycled sortie takes 6 hours without planning aids and only 3 hours with aids. The pilot capacity of each F/A-18 squadron is increased from 26 to 42 sorties.

Another means to husband aircrew resources is to use an Operational Strike Planning Cell (OSPC) to perform most of the mission planning. During the 1997 *Nimitz* Surge, USS *Nimitz* and CVW-9 were augmented by an OSPC.²¹ The OSPC planned interdiction missions from launch to IP, conducted targeteering, prepared mission packages for the strikes, coordinated the tanking plans, briefed the strike leaders on the missions, and coordinated the administrative functions supporting air interdiction and close air support execution. They also served as a bomb damage assessment (BDA) cell. The OSPC removed a major workload from the aircrew, maintained planning continuity, and coordinated the strike campaign with the Joint Force Air Component Commander (JFACC) and the Joint Air Operations Center (JAOC). By reducing the time strike leaders spent in the carrier intelligence center (CVIC), the OSPC significantly increased the number of strike missions that could be executed and reduced pilot fatigue.

In the U.S. Navy, individuals outside the strike group do not typically plan missions. The consequences of this unfamiliarity were evident during the *Nimitz* Surge—the OSPC was initially held at arms' length until it was able to prove its worth to the strike leaders. Indeed, there were a few strike leaders on board USS *Nimitz* who did not embrace the OSPC. For these few, the OSPC was a hindrance more than a help, for they dismissed the OSPC's products and conducted their own strike planning. For future high-intensity operations, the broad acceptance throughout naval aviation of NSAWC's strike syllabus makes planning strikes, at least the portions not over enemy territory, somewhat rote. This argues for the acceptance of a group like the

21. The OSPC on board USS *Nimitz* comprised 10 strike warfare specialists (O-1 through O-6). Based on the USS *Nimitz* experience, the recommended size of the OSPC is 17 (14 officers and 3 enlisted) personnel.

OSPC. Strike leaders will still need to participate in strike planning, especially in high-threat scenarios. The strike packages' survival may depend upon the strike leader's awareness of his contingency options. Integration of an OSPC into the air wing operations requires clearly articulated operating procedures that have the endorsement of the air wing, CVIC, and the OSPC.

Post-mission procedures require aircrew to debrief maintenance on aircraft performance, CVIC on mission execution, and fellow air wing aviators on tactical execution. These debriefings can consume one to two hours and frequently ask for redundant information. Streamlining this process by ensuring that the debrief information is shared among the shipboard recipients and that the aircrew are the only or best source for the information can increase pilot sortie-generation capacity.

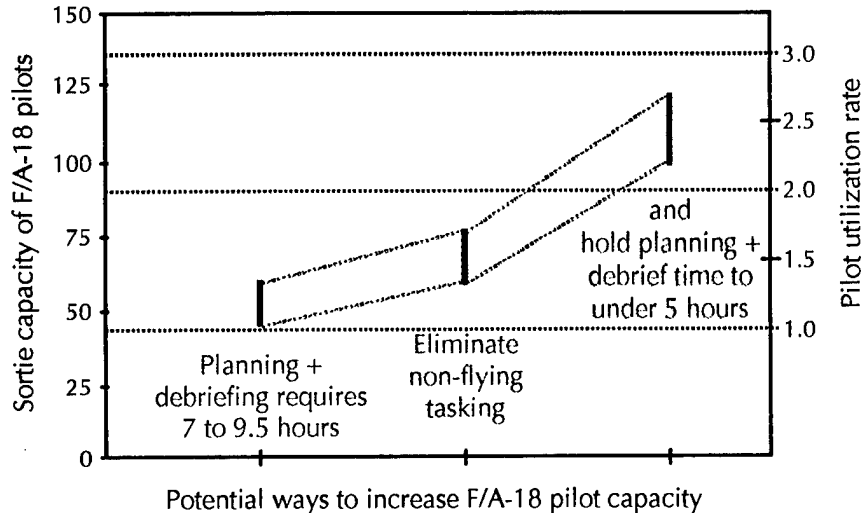
New systems are in test and development which automatically tap into an aircraft's computer and download data when the aircraft comes in range of the carrier—before recovery. Such systems would not only speed the receipt of BDA, but provide CVIC with more accurate information than is possible from a face-to-face aircrew debrief. Debriefs of aircrew could be specifically tailored in real time in light of the automated data already received on board. This additional information could be obtained from face-to-face debriefs with the aircrew or possibly over the radio while the aircraft is in the marshal pattern awaiting to land.

In addition, these new systems can download data directly to the squadron maintenance departments to speed their preparation for the arrival of the aircraft. The maintenance department could use this time to break out spare parts from the parts lockers or cannibalize aircraft, reducing the time returning aircraft spend awaiting spare parts and increasing the mission capable (MC) rates of aircraft.

Figure 21 illustrates the potential gains in F/A-18 pilot capacity by eliminating the non-flying tasking of pilots and reducing the time spent in mission planning and debriefing. Even if the cap on pilot utilization rate chosen for a specific operation remains unchanged, reducing the time pilots spend in pre- and post-mission activities will increase the time available for crew rest and reduce fatigue. In

general, this will increase performance and potentially lower combat attrition.

Figure 21. Potential gains in F/A-18 pilot capacity



Pool F/A-18 pilots

After a few days of high-intensity flight operations, the three F/A-18 squadrons will likely experience different pilot utilization rates. This may be due in part to differences in initial manning, the number of pilots on medical flight status or lost in combat, or the availability of squadron aircraft for the pilots to fly. Provided the F/A-18 pilots in one squadron are qualified to fly the blocks of F/A-18s in a sister squadron, pooling the resources of the three squadrons ensures that aviators from each squadron are tasked equally to fly missions, have similar times to prepare for those missions, and receive the same amount of rest. In this way, pooling can increase the overall capacity of the air wing to generate F/A-18 sorties.

Reduce fatigue of pilots

Reducing the fatigue of pilots may allow their tasking to be increased. Even if a gain in sortie capacity is not achieved, reducing pilot fatigue may increase their proficiency. A key ingredient to this is the establishment of a battle rhythm. In addition, scheduling flights so that a pilot's missions are consolidated into as small a period of time as possible will maximize the time available for uninterrupted crew rest. During the 1997 *Nimitz* Surge, pilots expressed preference for this scheduling scheme. Providing healthy diets, encouragement to exercise, and easy access to e-mail may also reduce the stress levels of all individuals.

Augmentation—pilots and support personnel

The Navy is developing plans to augment the air wing in times of crisis with additional F/A-18 pilots. The feasibility of augmenting an air wing with pilots remains to be determined in a real world operation. Commercial air carriers might be able to transport the pilots into theater and thus minimally impact the military air lift. Operators speculate that it would require 6 to 9 days from the time a decision was made to send the additional pilots to their arrival on board the carrier.

The value-added of augmentation was seen during the 1997 *Nimitz* Surge when CVW-9 was augmented to 22 F-14 pilots and 79 F/A-18 pilots. With the augmentation, the strike/fighter pilot utilization rate was 2.1; had CVW-9 had to execute the Surge operating tempo while on deployment, the pilot utilization rate would have been 3.1.

For augmentee pilots to contribute to their full potential, they must be able to integrate quickly and efficiently with the resident personnel. During the 1997 *Nimitz* Surge, the integration of the augmentee pilots into flight operations was relatively seamless. This was attributed to the adoption of the NSAWC strike syllabus throughout the strike community. However, for new members on any team, earning the confidence of the resident personnel is critical. One of the recommendations derived from the 1997 *Nimitz* Surge was to identify the augmentees before the carrier and air wing workup period. This practice would allow the augmentees to participate in the workups,

establishing relationships with the resident personnel and building the foundation of a cohesive team.

Ideally, the F/A-18 pilots sent to augment the air wing would be not only carrier-qualified, but also proficient in the specific blocks of F/A-18s resident on board. Future implementation plans may have to include a means for identifying and tracking such groups of supplemental pilots for each deployed air wing.

Even if not fully carrier-qualified, the additional pilots can perform many of the collateral duties of embarked pilots such as: LSO, watch standing, strike planning, and BDA. Indeed, this was the case during the *Nimitz* Surge when five aviators were sent to augment CAG LSOs. Also as we discussed earlier, the OSPC conducted much of the strike planning and BDA. None of these augmentees flew a single sortie during the *Nimitz* Surge. However, through their efforts, the squadron pilots' workloads were eased, which allowed them to fly a greater number of strike sorties per day.

Determining augmentation size: example

Provided a scheme for augmenting pilots can be developed, the number of pilots needed depends on the operational situation and requirement. We can adapt the base case estimates to specific scenarios to determine the number of aircrew needed. The following example illustrates how this can be accomplished.²²

How many F/A-18 pilots should be sent to augment the base case air wing to increase the pilot capacity to 150 sorties? The battle group commander has capped the pilot utilization rate at 2.0.

- Determine the man-ups to sorties flown ratio. In the base case we used 0.95 as the proportion of man-ups that result in sorties. For other scenarios, use the proportion that best describes the situation. For instance, when spares are manned extensively, a much smaller number should be used. A reasonable gouge for this proportion is:

22. Because the number of man-ups and pilots required must be integers, these computations must always be rounded up.

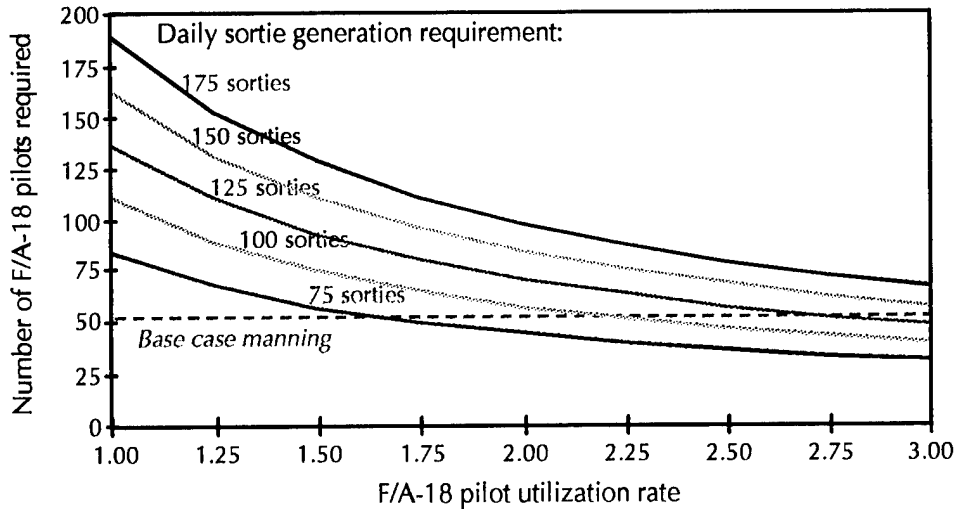
$$\frac{\text{number of sorties scheduled}}{\text{number of sorties scheduled} + \text{number of spares scheduled.}}$$

- Determine the number of man-ups needed. Divide the desired number of sorties by the man-ups to sorties flown ratio. In this case, the number of man-ups needed is 158 ($= 150 / 0.95$).
- Determine the minimum number of pilots needed to fly sorties. Divide the number of man-ups by the pilot utilization rate. In this case, a minimum of 79 ($= 158 / 2.0$) pilots are needed to fly sorties.
- Determine the minimum number of pilots needed to perform all duties. Add the number of pilots needed for non-flying tasks to the number needed to fly sorties. In this case, 3 pilots are needed for LNO duties. Thus, a total of 82 ($= 3 + 79$) pilots are required. Figure 22 shows the relationship among F/A-18 pilot utilization rate, the number of pilots available, and the required sortie generation under the assumptions we made for the base case.
- Determine the augmentation size. Subtract the number of pilots resident in the air wing from the number that are required. In this example, at least 31 ($= 82 - 51$) F/A-18 pilots should be sent to augment the air wing. Sending more than 31 pilots would ease workloads, which may increase aircrew proficiency and provide a buffer against the loss of aircrew due to combat attrition, accidents, or illness.

Tap other onboard, qualified aviators

Members of the air wing staff, embarked flag staff, and ship's company may also be qualified to pilot aircraft. Where feasible, this resource may be tapped—essentially, it is an in-house augmentation cell. However, the availability of these aviators may be very limited. In times of crisis, they may be fully tasked with their assigned jobs. In addition, these aviators may not be fully current in carrier operations and tactical execution. Even so, it may be worthwhile to monitor their availability.

Figure 22. Number of F/A-18 pilots required for specified levels of sortie generation



NOTE: Assumes 3 pilots are TAD and the man-ups to sorties flown ratio is 0.95.

Reduce the number of spares manned

Each spare manned is insurance that a specific sortie will be flown. This insurance does have a cost—an expenditure of an aircrew man-up that may not result in a sortie. If aircrew are found to be the limiting factor to the sortie-generation capacity of the carrier and the air wing, reducing the number of spares manned may increase the number of sorties flown. The operational commander must determine whether ensuring specific missions are executed is worth the cost of fewer sorties generated.

Reduce the amount of crew rest

The base case assumed crews required 9 hours of rest each day. Reducing the time spent resting will allow higher utilization rates and increase pilot capacity. Nevertheless, this action should be done with caution and only for a very limited period. Sending fatigued aircrew into combat may result in increased accident rates and attrition.

Flight deck capacity

The capacity of the carrier and air wing to ready, launch, and recover aircraft is determined by four factors:

- The number and type of crews working the flight deck.
- The load and air plans.
- The number and type of aircraft, ordnance, and general service equipment (GSE) on the flight deck.
- The construction and transfer of ordnance from the magazines to the flight deck.

The conduct of flight operations involves the intricate orchestration of aircraft and people. Within each cycle, aircraft are launched and aircraft from previous launches are recovered. After an aircraft lands, it is directed to the de-arm area where unexpended ordnance (primarily air-to-air weapons) are safed and then the aircraft is moved to an initial spot on the flight deck until the recovery is complete. Some aircraft remain at their initial locations while others are towed to new spots on the flight deck. Fuels crews fill the aircraft with JP-5, maintenance crews service the aircraft, and ordnance crews load weapons on the aircraft. Concurrent with these actions, non-mission capable (NMC) aircraft are repaired or exchanged with mission capable (MC) aircraft from the hangar bays, weapons and consumables are transported to the flight deck, and empty weapons skids are returned to the magazines. Finally, readied aircraft are towed to a position ready for the next launch and their weapons are armed.

We use data on the time required to complete individual turnaround functions to estimate the typical time required to ready an aircraft for launch. We translate this required time into the number of aircraft that can be readied within a cycle and, ultimately, throughout the flight day. Our estimate of the capacity of a flight deck to accomplish

these tasks includes the need to build weapons and transport them from the magazines to the flight deck.

Capacity of the flight deck in the base case

We found that under most circumstances, the loading of ordnance on strike/fighters is by far the most constraining component of flight deck operations. Table 26 shows our estimate of the capacity of air wing ordnance crews to configure strike/fighters with different types of heavy air-to-ground ordnance.²³

Table 26. Daily capacity of ordnance crews to ready strike/fighters within an 18-hour flying day

Air-to-ground configuration	F-14 sorties				F/A-18 ^a sorties				Comments
	1+15	1+20	1+30	1+45	1+15	1+20	1+30	1+45	
2 Mk 82 GP or 2 Mk 83 GP	17	18	19	21	35	36	38	40	Loaded manually with hernia bar.
2 Mk 84 GP, 2 Rockeye, or 2 Gator	12	12	13	15	25	26	27	28	Loaded with hoist.
2 JSOW	n/a	n/a	n/a	n/a	25	26	27	28	Loaded with hoist.
2 LGB	7	8	9	9	16	16	17	18	Loaded with hoist. Electrical mating with aircraft required.
2 Maverick, 2 HARM, or 2 SLAM	n/a	n/a	n/a	n/a	16	16	17	18	Loaded with hoist. Electrical mating with aircraft required. Special initialization procedures required.

a. Each squadron.

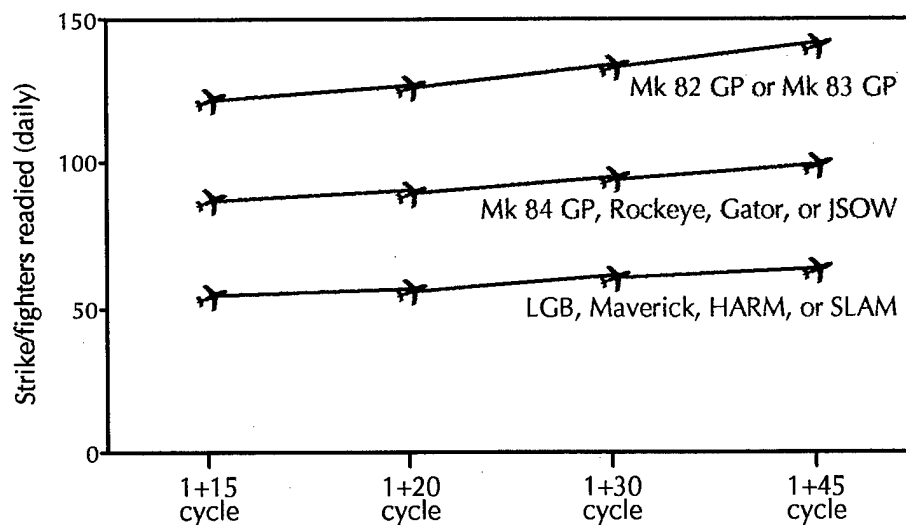
NOTE: First two launches readied before flight operations begin.

23. Not all strike/fighters will be tasked to deliver air-to-ground ordnance. Additional strike/fighter sorties are needed to support the strike missions. For example, during the 1997 *Nimitz* Surge, only 75 percent of the F-14 sorties and 85 percent of the F/A-18 sorties carried bombs to the target. The remainder of the strike/fighter sorties flew strike escort and SEAD missions.

The sorties that deliver ordnance on enemy targets are the core of the strike packages. Other aircraft in the strike packages support the aircraft that deliver ordnance by performing such missions as fighter support, SEAD, and command and control. We found that preparing these other aircraft for flight is rarely limited by the operations on the flight deck. Rather, the conduct of these missions are typically constrained by the number of air crew and aircraft available.

We estimate that in our base case the fuels crews can fuel at most 300 fixed-wing aircraft in an 18-hour day. These 300 refuelings must meet the needs of not only the strike/fighters that deliver ordnance, but all fixed-wing aircraft. Figure 23 shows the total number of strike fighters that can be readied for launch with ordnance in an 18-hour flight day. In all cases, fewer than 150 strike/fighters can be readied with ordnance, significantly lower than the capacity of the fuels crews to refuel aircraft. We conclude that refueling operations should not constrain CV/CVW firepower under most operational circumstances.

Figure 23. CV/CVW capacity to ready strike/fighters with air-to-ground munitions during an 18-hour flying day



NOTE: Each aircraft is configured with two air-to-ground munitions.

We caveat our results as follows:

- These estimates are unconstrained by the need to have MC aircraft on the flight deck for crews to ready or aircrew available to fly those aircraft.
- Observed performances should be expected to vary (both above and below) our estimates of flight deck capacity.
- These estimates should not be scaled proportionally to estimate the turnaround capacity for longer flight days for two reasons. First, while flight operations conclude after 18 hours, the flight deck crews' work day is several hours longer. Whatever time remains is needed for those individuals to rest. If the flight day is extended, the rate at which strike/fighters can be readied will decrease. Second, a significant factor in our estimates is that the aircraft scheduled for the first two launches are readied before the flight day begins. The relative benefit to longer flight days will be less.

Four key factors drive these estimates:

- Each strike/fighter squadron has only one bomb crew on the flight deck to load ordnance on their aircraft. Loading of squadron aircraft must be done in sequence.
- Loading weapons other than Mk 82 GP and Mk 83 GP bombs requires a weapons hoist.
- Loading the F-14 with ordnance is more difficult and time-consuming than for the F/A-18.
- Special servicing cannot be done in conjunction with fueling and ordnance loading. In addition, electrical connections cannot be made during fueling.

For comparison to table 26, we provide in table 27 the comparable numbers of strike/fighters that could be readied during an 18-hour period using the turnaround rates demonstrated during the 1997 *Nimitz* Surge. While the numbers of sorties listed in the tables are very close, different operating conditions influenced the outcomes. During the *Nimitz* Surge, the flight deck crews were augmented

(increasing their capacity), but flight operations were conducted continuously for 98 hours (decreasing their capacity). These two factors tended to compensate for each other. In both the *Nimitz* Surge and in our estimates, however, the loading of ordnance on aircraft was the limiting component of the turnaround process.

Table 26 provides several insights into the turnaround processes:

- The longer the cycle, the larger the capacity of the ordnance crews. This is despite the fact that the number of cycles in an 18-hour flight day decreases with longer cycle times. This reflects the benefits of longer, uninterrupted periods to complete loading operations. In addition, longer cycles typically mean larger launches and recoveries, which provides the ordnance crews with longer rest periods.
- As expected, the capacity of the loading crews is less when aircraft must be configured with more sophisticated weapons, which require loading with a hoist and connecting to the electrical circuits of the aircraft's systems and sensors.
- The turnaround capacity of the F/A-18 squadrons is larger than that of the F-14 squadron. This result is because turnaround of the F-14s, in particular ordnance loading and servicing, is more involved and time-consuming. Also, because respots of the F/A-18s are frequently not required, turnaround for the F/A-18s can begin as soon as the aircraft shuts down. For F-14s, though, turnaround typically must wait a respot and, as a result, does not begin until after the recovery is complete.

Table 27. Number of strike/fighters readied using the 1997 *Nimitz* Surge turnaround rates

	F-14 sorties				F/A-18 sorties ^a				Other fixed-wing aircraft			
	1+15	1+20	1+30	1+45	1+15	1+20	1+30	1+45	1+15	1+20	1+30	1+45
Loaded with ordnance ^b	15	17	18	20	33	34	36	38	-	-	-	-
Not loaded with ordnance	6	7	9	10	9	10	11	11	32	34	36	38
Combined	21	24	27	30	42	44	37	49	32	34	36	38

a. Each squadron.

b. Two Mk 82 GP or two Mk 83 GP.

Aircraft turnaround

The process of readying aircraft for launch is quite complicated. We will briefly outline the major steps in this process, highlighting those factors that contribute to limiting the turnaround capacity of the flight deck. Further detail on the turnaround process can be found in the appendix [1] (published separately).

Time available

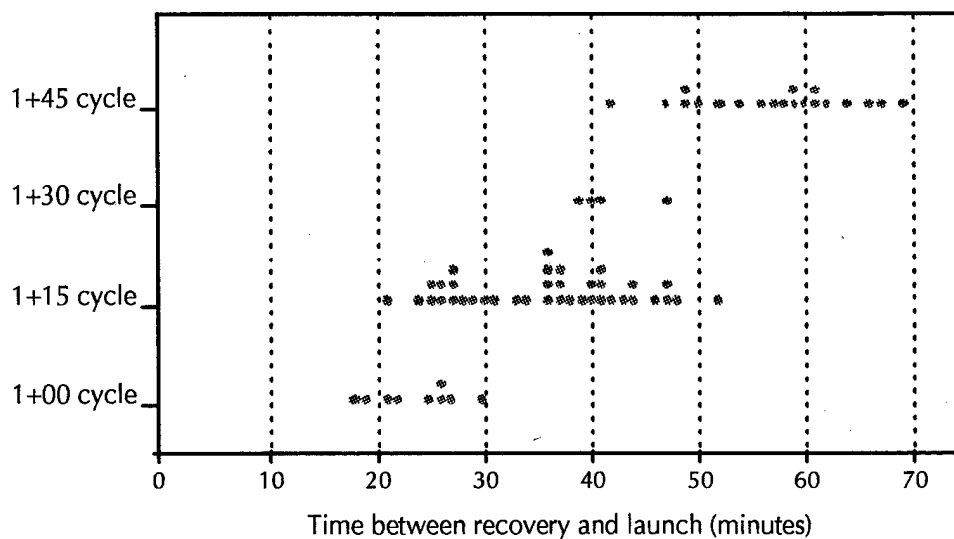
While some turnaround functions are conducted while aircraft are being launched and recovered, they are limited. The flight deck crews are most active in the period between recovery and launch. The length of this period is critical in assessing the turnaround capacity of the flight deck and is influenced most by the cycle time and the size of the launch and recovery, but can also be affected by other factors such as aircraft bolters or malfunction of the SPN 46. As a rule of thumb, it takes 30 to 60 seconds to launch an aircraft (four catapult CV) and 60 to 75 seconds to recover an aircraft [22]. Figure 24 shows the time between the conclusion of recovery and the start of launch seen during the *Nimitz* Surge. Cycles of 1+00 averaged 25 minutes; 1+15 cycles averaged 35 minutes; 1+30 cycles averaged 42 minutes; and 1+45 cycles averaged 57 minutes. The time between recovery and launch did not grow commensurate with the cycle time. For every 15-minute increment in cycle time, the time between recovery and launch grew by about 10 minutes. This is in part due to differences in the number of aircraft launched and recovered (figure 25). The uninterrupted time to ready aircraft is shortened further by the requirement to start the aircraft's engines (typically 15 to 20 minutes) before launch.

Respot, fueling, and servicing processes

Respot is time and manpower intensive. To respot an aircraft, it must be unchained and unchocked from the flight deck, towed using a tractor, and finally rechained and rechecked in its new location. It requires a minimum of three aircraft directors, a plane captain, and a tractor operator. According to [23], the towing of a single aircraft aft takes between five and seven minutes. The reliability of the tractors is historically low—typically averaging about 50 percent.

Aviation fuel is supplied by fueling stations on the flight deck and in the hangar bay. USS *Nimitz* has 14 flight deck fueling stations, for a total of 28 hoses.²⁴ There are 5 fueling stations in the hangar bay, but these were typically used for defueling aircraft. The fueling stations are arranged such that it is possible to fuel aircraft almost anywhere on the flight deck [24].

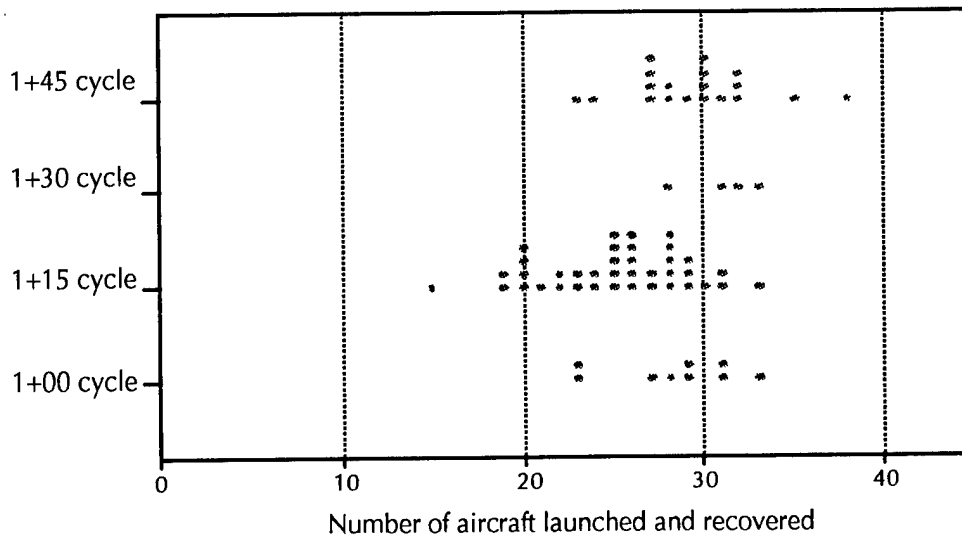
Figure 24. Time between recovery and launch during the 1997 *Nimitz* Surge



There are usually six to eight fuels teams on board. Each team consists of one supervisor and two fuelers. The supervisor operates the deck-edge controls; the fuelers move the hoses to the aircraft, engage the hose to the aircraft, transfer the fuel, disengage the hose, and move the hose to the next aircraft. In this way, one team can fuel two aircraft simultaneously from a single fuel station.

24. The number of stations on the flight deck on *Nimitz*-class carriers varies between 14 and 18. Each station has 2 to 4 hoses.

Figure 25. Operating tempo by cycle length during the 1997 *Nimitz* Surge



Fueling operations typically start about 15 minutes after the first aircraft recovers. A thousand pounds of JP-5 can be pumped in about one minute [24] when the pressure from the fueling station is at levels normal for the carrier. This pressure can be maintained whenever the number of aircraft concurrently receiving fuel is less than 5. As the number of aircraft being fueled increases, the pressure drops and the length of time required to pump 1,000 pounds of JP-5 increases. Fleet operators have indicated they can discern a significant difference in the time required to transfer fuel when the number of aircraft approaches 10. Engaging and disengaging the hose typically takes about 5 minutes. The maximum fuel capacities of air wing fixed-wing aircraft are shown in table 28, along with the bounds on the fueling times for these aircraft. Transitioning to another pair of aircraft typically takes the fuels crews between 5 and 10 minutes. In addition to the fixed-wing aircraft in the air wing, the fuels crews also service rotary aircraft. Occasionally, fueling an aircraft is disrupted and hoses must be disconnected and subsequently reconnected, increasing the time required to complete the fueling. We estimate that 8 fuels crews working an 18-hour day can service up to 300 fixed-wing aircraft.

Table 28. Aircraft fuel capacities

Aircraft type	Maximum internal and external fuel capacity (klb)	Maximum time needed to fuel ^a (minutes)
F-14	20.0	25
F/A-18	17.6	23
EA-6B	25.4	31
E-2	12.4	18
S-3 / ES-3	17.0	22

a. Includes time to engage hoses, transfer fuel, and disengage hoses.

Once chocked and chained, aircraft are serviced by a squadron plane captain. Most service tasks can be performed in parallel with weapons loading and fueling and usually can be completed in the time needed to load weapons and fuel the aircraft.

Ordnance process

The most involved of the turnaround processes is ordnance handling. The ordnance process begins long before the aircraft lands. It starts in the carriers' magazines where weapons are broken out of inventory and built up. The weapons are transferred to the flight deck, frequently via staging areas in the mess decks and hangar bays. A limited number of weapons can be stored on the flight deck in the bomb farm. Air wing ordnance crews retrieve the weapons from the bomb farm and load them on awaiting aircraft on the flight deck.

The ordnance loading process is also the one for which the least amount of quantitative data are available. Peacetime provides few opportunities to stress and evaluate the loading procedures during high-intensity flight operations. Qualitatively, we know the time to load an aircraft depends on the ordnance involved, the number of crews working, and the configuration of the aircraft before loading starts. For example, to configure an F/A-18 or EA-6B with HARM, the launcher must be removed from the aircraft and taken to the magazines to load. Even when launchers can remain on the aircraft, they require servicing after a few firings. Loading can also be affected by other factors such as where the aircraft is spotted. For instance, to load sidewinder missiles on the wing tip station of an F/A-18, the

wings need to be spread. In these cases, coordination is critical between the flight deck personnel (who are responsible for moving aircraft) and the bomb crews (who are responsible for loading ordnance). Unfortunately, most data on the loading process are anecdotal—we know of only a few studies that measured operational performance.

Moving weapons from the hangar deck to the flight deck is frequently the most difficult step in transporting weapons from the magazines to the awaiting aircraft and is vulnerable to interruption. The demand for ordnance during high-intensity flight operations can easily exceed the ability of the weapons elevators to transport. The deck-edge elevators can be used to transport some, if not all, of the ordnance. However, a variety of operating conditions, such as sea state conditions or carrier turns, can prevent deck-edge elevator runs and interrupt the flow of bombs to the flight deck. For this reason, it is critical that requests for an elevator run be caveated by their time urgency.

Air wing ordnance crews are responsible for loading ordnance, external fuel tanks, and pods. Typically, an F-14 squadron has 28 ordnance personnel and each of the F/A-18 squadrons has 20. The general order to loading ordnance on aircraft is:

- Aircraft recover and taxi to the de-arming area.
- Air-to-air weapons are de-armed.
- Aircraft taxi to their assigned spot.
- Ordnance crews move bombs from the bomb farm to the aircraft as it reaches its final spot. For weapons other than the Mk 82 and Mk 83, a skid can hold only one bomb.
- Aircraft are shut down and secured.
- Spent cartridge actuated devices (CADs) are removed from the bomb racks.
- Bombs are positioned under the aircraft's racks on skids and hoisted into position. Mk 82 GP and Mk 83 GP weapons can be loaded manually; other weapons require a powered hoist.

- The ordnance crew moves the bomb skid to the next aircraft station to be loaded and begins loading the second bomb while an arming crew remains to install the arming wire on the first bomb.
- Once all bombs are loaded and armed, the bomb skid(s) is returned to the bomb farm and a quality assurance inspection is completed by the ordnance crew.

We based our estimates of the average time spent by an ordnance crew to configure a strike/fighter with weapons on fleet data collected during no-notice missile exercises, the 1997 *Nimitz* Surge, and the Carrier Air Wing Eleven (CVW-11) weapons det to NAS Fallon in April and May of 1998. These times (shown in table 29) proved to be the overall limiting factor to the capacity of the flight deck to ready aircraft and were the primary factor in our estimation of the capacity of ordnance crews to load aircraft with air-to-ground ordnance (table 26). Several operating conditions can increase the time required to configure an aircraft. Night operations increase the time required, as does sea state (a pitching deck can make all operations on a flight deck more difficult and time-consuming) and inclement weather. For extended high-intensity operations, the fatigue incurred by the bomb crews may also become a significant factor. The occurrence of any of these conditions will lower the capacity of the flight deck.

Launch and recovery operations

Data on the time required to launch and recover aircraft are routinely collected on every carrier deployment. Figures 26 and 27 show launch and recovery data typical of most carrier experiences during routine flight operations, when flight-deck management was not stressed to its limits.²⁵ As such, estimates of the time required to launch and recover aircraft based on these operational data can only be viewed as over estimates of the minimum times required. Further, the data shown in these figures are an amalgamation of day and night

25. This data was collected over a six-day period on flight-deck operations on board USS *America* during its pre-deployment exercise and reported in [22]. Weather conditions during this period were very favorable—clear skies and calm seas.

operations, although data taken during the daylight hours predominate.

Table 29. Average time required by ordnance crews to configure strike/fighters with weapons

Air-to-ground configuration	Average time ordnance crews spend (minutes)	
	F-14	F/A-18
2 Mk 82 GP or 2 Mk 83 GP	22	14
2 Mk 84 GP, 2 Rockeye, or 2 Gator	33	20
2 JSOW	n/a	20
2 LGB	50	30
2 Maverick, 2 HARM, or 2 SLAM	n/a	30

NOTE: Crews are not augmented.

Figure 26. Time expended launching an aircraft

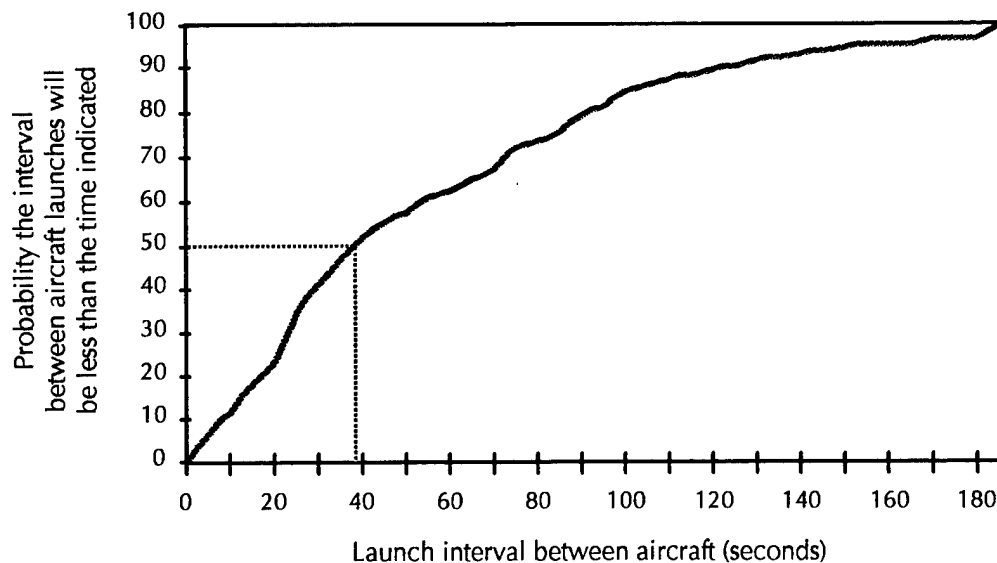
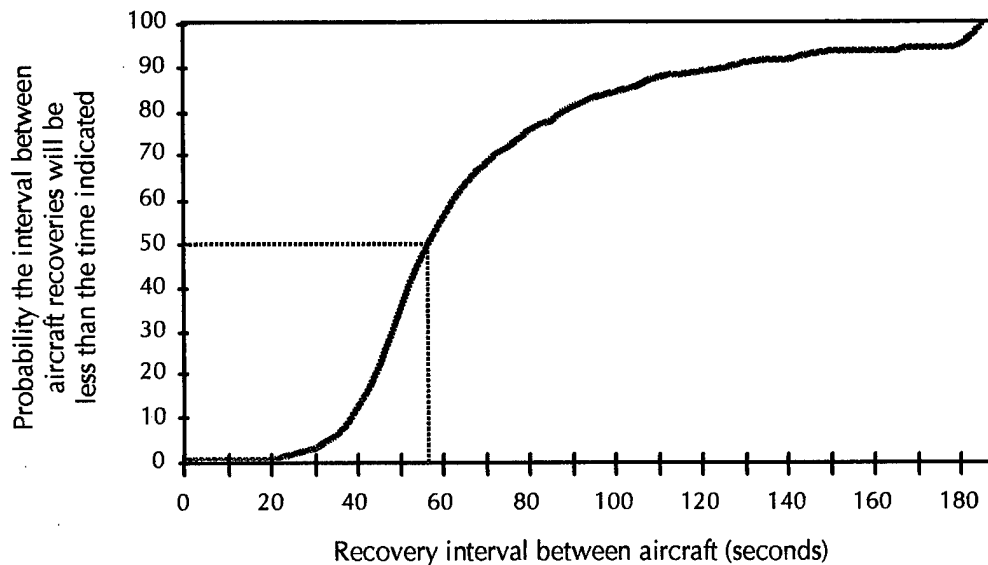


Figure 27. Time expended recovering an aircraft



During the 1997 *Nimitz* Surge, CVW-9 experimented with a new recovery pattern for Case I and Case II day operations [3]. Because of this, we felt that the launch and recovery data of the *Nimitz* Surge might not be indicative of fleet capabilities and decided not to include it in our analysis.

Other factors affecting flight deck capacity

During high-intensity flight operations, routine foreign object damage (FOD) walkdowns must be conducted frequently. Combat FOD walkdowns occur when the flight deck is unintentionally littered with debris. During FOD walkdowns, flight operations cease and all available flight deck personnel participate; FOD walkdowns are disruptive to flight operations and the turnaround process.

We assessed the reliability of ship aviation systems critical to the success of high-intensity flight operations and how the failure of these systems affects the sortie-generation process. We found:²⁶

- *Catapults*. Although extended failures of two catapults are not likely, if this does occur, in particular when one of the failed

catapults is at the waist, the time to launch aircraft will increase significantly. This will reduce the time available between recovery and launch, which in turn decreases the turnaround capacity of the flight deck.

- *Arresting gear.* Maintenance on the arresting gear (such as changing cables) can be performed without any noticeable effect on flight operations.
- *Radars.* As long as one of the two channels of the SPN 46 is functional, recoveries should not be adversely affected.
- *Elevators (weapons and deck-edge).* Deck-edge Elevator Two is critical for the supply of ordnance to the flight deck. A severe casualty of this system would adversely affect the flow of ordnance and reduce the rate at which ordnance crews could ready aircraft.
- *Aircraft Electrical Support System (AESS).* The AESS provides plug-in power to start aircraft in the hangar bay and on the flight deck. Overlap and availability of the stations is sufficient that flight deck operations should not be degraded by a failure of one of the AESS stations.
- *GSE.* Several pieces of gear are critical to the readying of aircraft—the weapons hoists, the tractors, and the bomb skids. The availability of the tractors and bomb skids should not affect turnaround operations. However, the number of operable gas-powered weapons hoists may limit the rate at which aircraft are loaded with ordnance.

When might the flight deck capacity be less?

Flight operations conducted 24 hours a day

Longer flight days require ordnance personnel to work a shift rotation. With smaller ordnance crews working the flight deck, the rate at

26. Additional details can be found in the appendix [1] (published separately).

which strike/fighters can be configured with ordnance in a cycle is reduced. Table 30 shows our estimates of the capacity of ordnance crews to configure strike/fighters with ordnance when flight operations are conducted for 24 hours. Note that the number of aircraft readied during 24-hour operations is less than during 18-hour operations.

Table 30. Daily capacity of ordnance crews to ready strike/fighters within a 24-hour flying day

Air-to-ground configuration	Capacity of ordnance crews to configure strike/fighters							
	F-14 sorties				F/A-18 ^a sorties			
	1+15	1+20	1+30	1+45	1+15	1+20	1+30	1+45
2 Mk 82 GP or 2 Mk 83 GP	15	16	17	18	30	31	33	36
2 Mk 84 GP, 2 Rockeye, or 2 Gator	12	13	13	15	21	22	24	25
2 LGB	9	9	9	10	14	14	16	17
2 HARM, 2 Maverick, or 2 JSOW	n/a	n/a	n/a	n/a	14	14	16	17

a. Each squadron.

Permit sortie-completion rates as low as 85 percent

Lowering the acceptable sortie-completion rate will demand that the flight deck crews be more flexible. A greater level of confusion by flight deck crews can be expected, at least until procedures are developed; as a result, flight deck capacity will suffer, at least in the short term.

Strike/fighters configured with more ordnance or their ejection racks must be changed frequently

Loading strike/fighters with more than two bombs will decrease the number of strike/fighters readied. For example, configuring aircraft with four heavy bombs essentially halves the rate at which strike/fighters can be readied, which was the primary limiting factor to flight deck capacity. Similarly, when aircraft ejection racks or rails

must be reconfigured to accommodate employment of a variety of weapon carriages on different cycles, the turnaround process is slowed.

Gun loading

Loading a strike/fighter's guns requires two or three ordnancemen. Individuals engaged in gun loading are not available to load aircraft with other weapons. Without augmentation, the loss of two to three ordnancemen from the weapons loading team could severely slow the bomb loading process. The time required to load an aircraft gun is at least 20 minutes, and can be as long as 45 to 60 minutes if rounds jam the loading equipment.

Failure of weapon hoists

The reliability of the HLU-196 weapons hoist during peacetime, low-intensity operating tempos has historically hovered around 50 percent. With 18 weapons hoists on board, only 9 hoists can be expected to be operational at the beginning of hostilities and the number of working hoists should fall with their use. In our computations, we assumed that two hoists were allocated to each of the strike/fighter squadrons and the third to the EA-6B squadron. These are the minimum number of hoists each of these squadrons' ordnance crews needs to do their job. If just one hoist fails during the operation, the capacity of the squadron is cut in half.

Cycle times less than 1+15

Our estimates of flight deck capacity indicated that capacity decreased with cycle time. There appears to be a limit on how short a cycle can be before the turnaround process breaks. During the *Nimitz* Surge, the flight deck on a few occasions transitioned to a 1+00, 1+00, 1+45 template. In practice, the 1+00 cycles proved exceptionally challenging, nearly forcing the flight deck into operating in a flex-deck mode. The 1+00 cycle appeared to increase the pressure on personnel significantly, which in turn seemed to exacerbate fatigue. While crews managed to ready their quota of aircraft in the first 1+00 cycle, the following 1+00 was too short and on three of six attempts, operators in real-time slid the template to 1+00, 1+15, 1+30. The overall

assessment from these operators was that under a high-intensity operating tempo, such as demonstrated during the *Nimitz* Surge, the cycle time should be at least 1+15.

Even the 1+15 cycles at times proved challenging during the *Nimitz* Surge. On six 1+15 cycles, a few aircraft had to be launched after the recovery began. This indicates that the flight deck crews had insufficient time to turn aircraft around before the "must start" time of the recovery.

The limit to cycle time is more pronounced during night operations. At night, several factors reduce the time available for aircraft turnaround: recovery times are longer, aircraft and ordnance movement on the flight deck are slower, and boarding rates are decreased. These factors all reduce the time between recovery and launch. If they occur during a short cycle, the flight deck crews have less time to recover from their adverse affects.

Flight deck density

The greater the congestion on the flight deck, the more difficult and time-consuming turnaround functions become. During the *Nimitz* Surge, to keep the flight deck density within workable tolerances, MC aircraft frequently were kept in the hangar bay and, on some occasions, MC aircraft were transferred from the flight deck to the hangar deck. By the end of the *Nimitz* Surge, USS *Nimitz* and Carrier Air Wing Nine (CVW-9) felt that the optimum number of aircraft on the flight deck was 25 (for a loading of 50 percent). In the near term, with 4 fewer F-14s on board, the carrier and air wing will have greater flexibility in deck loading. Because the F-14 is a larger aircraft than the F/A-18C, the carrier may be able to manage a larger number of mission-capable F/A-18Cs on the flight deck.

Manning not at billets authorized

During peacetime, the level of manning specified by the number of billets authorized (BA) establishes the manning requirements for each job type. Currently, actual manning is typically about 5 percent below the BA level. This places incredible stresses on the execution of flight deck operations. Any further reduction will have a direct

impact on the ability of the carrier and the air wing to generate fire-power.

Need to replenish

The aviation fuel stores and ordnance inventory of the carrier determine the number of days that the carrier can continue to operate before pausing to replenish. Replenishment cannot be conducted during high-intensity flight operations. While in the base case flight quarters are conducted for only 18 hours, the flight deck crews man stations and move transferred goods during the replenishment. At the turnaround rates we estimated, the flight deck crews cannot be expected to perform replenishment immediately following flight operations. If replenishment is required, the operating tempo must be decreased.

Deck-edge elevators not available to transfer ordnance and skids

Elevators were key to the transference of ordnance to the flight deck. Although flight operations do not prohibit elevator usage during high-intensity flight operations, many situations can delay elevator operation:

- The carrier is in a turn or moving too fast.
- An aircraft scheduled for an impending launch is parked on the elevator.
- Ordnance remains to be loaded on the elevator.
- An aircraft on the elevator is nose- or tail-over-deck, not chained down, or is turning.
- An aircraft next to the elevator is fouling the elevator's stanchions.
- There are not enough aviation boatswain's mates to man the elevator.
- An aircraft on the elevator destined for the hangar bay is configured with ordnance or has JP-8 taken from an Air Force tanker.

- Using the elevator would foul the landing area (Elevator Four).
- The hangar doors are closed.
- The hangar bay could not take the down traffic.

Hazards of electromagnetic radiation to ordnance conditions

Hazards of electromagnetic radiation to ordnance (HERO) conditions on the flight deck can restrict the use of flight deck radio traffic. In these situations, all operations on the flight deck take longer, which reduces the flight deck capacity.

How can the flight deck capacity be increased?

Fleet experience during high-intensity flight operations and our analysis come to the same conclusion—people, not the machines they operate, limit the flight deck capacity. Any increase in the efficiency and productivity of the crews will have a direct effect on the firepower they can generate. Sharing the workload among the F/A-18 ordnance crews may improve their overall rate of loading weapons. Working the flight deck is difficult, stressful, and physically demanding. As the operation progresses, flight deck crews may become fatigued and their productivity fall. One way to counteract this is to create a working environment that minimizes their fatigue. Lastly, bringing additional personnel on board to augment the flight deck crews can significantly increase the firepower capacity of the carrier and air wing.

Pool F/A-18 resources

Although the objective of the battle group is to produce a steady stream of firepower, the relative tasking to the three F/A-18 squadrons to ready aircraft may vary from cycle to cycle. By pooling squadron ordnance crews, some efficiencies may be possible.

ORM considerations

To understand how to best counteract the effects of fatigue, the USS *Nimitz* Medical Department conducted an extensive study [21] of fatigue and proposed a number of fatigue countermeasures that

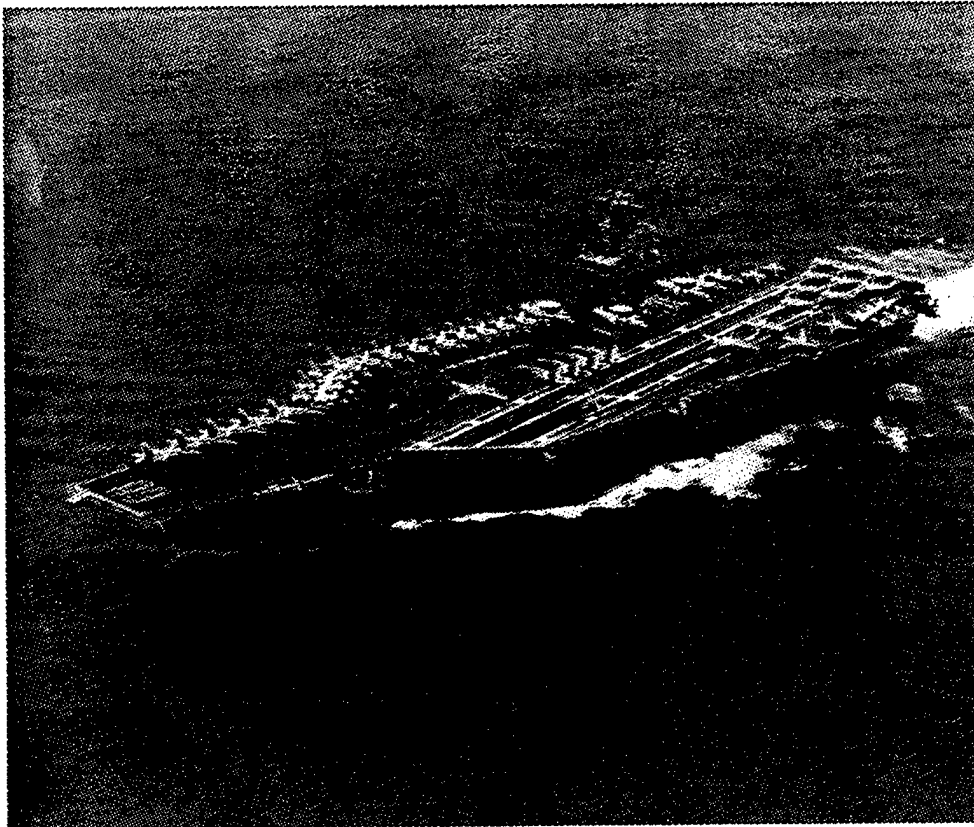
were subsequently incorporated into the *Nimitz* Surge. We summarize here those countermeasures that seemed most effective:

- Go into high-intensity flight operations well-rested. A person sleeping less than his daily requirement accumulates a sleep debt measured in cumulative hours. Personnel should try to eliminate any sleep debt before the operation begins.
- Schedule and allow naps. Naps reduce one of the predictors of fatigue, the number of hours of continuous wakefulness. Naps as short as 10 to 20 minutes have been shown to restore some performance.
 - During the *Nimitz* Surge, a policy permitting personnel to take naps in safe places near work areas was put in force.
- Pre-plan events and minimize last-minute changes. The effect of fatigue on complex decision-making is striking. To the extent possible, courses of action should be planned in advance to avoid situations that require mental creativity.
- Schedule events in anticipation of circadian cycle effects. A major decrease in alertness occurs daily between 0300 and 0500 as a result of the body's natural rhythm. Stressful activities should be avoided during this time period.
 - During the *Nimitz* Surge, the operating tempo was intentionally reduced during these early morning hours to reduce the stress on aircrew.
- If shift work is required, maintain or extend the work day. Shifting from day to night or simply shifting one's work/sleep cycle by a few hours can cause external and internal desynchronization of an individual's internal clock, resulting in fatigue. However, extending the work day is, in general, easier than reducing the work day by an equal amount.
- Minimize administrative and other non-critical duties. By reducing or postponing tasks that do not directly contribute to the creation of firepower, personnel can have additional time for rest.

- During the *Nimitz* Surge, USS *Nimitz* cancelled cleaning stations, inspections, and most administrative meetings.
- Ensure easy availability of food. Personnel will require food at non-standard times. The carrier departments should anticipate this need, and ensure easy access to meals at all times. Frequent, light snacks, as opposed to heavy meals, will keep energy levels elevated over extended work periods.
- During the *Nimitz* Surge, galleys were open 24 hours a day and hot food was provided at satellite feeding areas in various work centers.
- Reduce unnecessary interruptions to rest.
- During the *Nimitz* Surge, use of the 1MC was limited to only critical announcements. Man overboard and fire drills were suspended.
- Monitor fatigue and know when to quit. Personnel and their supervisors must acknowledge when they or their workers are fatigued and go to sleep. Fatigue is difficult to self-monitor; hence, supervisors need to be especially aware of its symptoms among their workers.
- During the *Nimitz* Surge, squadron medical personnel monitored aircrew fatigue and USS *Nimitz* Safety and Medical officers monitored the fatigue of the flight deck personnel. USS *Nimitz* also employed a series of surveys that allowed individuals to gauge, in real-time, their perceived fatigue.

Augment air wing ordnance crews and carrier air, weapons, and operations departments

One way to alleviate the overtasking of the individuals supporting flight operations is to bring additional, qualified personnel on board to assist them. The feasibility of doing this remains to be determined. The value-added, however, was demonstrated during the *Nimitz* Surge—with their augmentees, the USS *Nimitz* flight deck was able to generate 975 sorties over 98 hours.



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List of figures

Figure 1. CV/CVW firepower capacity guide	4
Figure 2. Number of strike/fighter sorties supportable by dedicating all air wing S-3s to tanker missions (mission times over 2 hours)	10
Figure 3. Mission overhead, flight time, and pilot utilization rate	11
Figure 4. Weapons expenditure	16
Figure 5. Increase in firepower with sufficient personnel augmentation	18
Figure 6. F-14D airframe capacity for the conduct of CFAS, strike, and TARPS missions	37
Figure 7. F/A-18 airframe capacity for the conduct of CFAS, strike, and SEAD missions	38
Figure 8. EA-6B airframe capacity for the conduct of SEAD and ECM missions.	38
Figure 9. E-2C airframe capacity for the conduct of command and control missions	39
Figure 10. S-3B airframe capacity for the conduct of tanker missions	39
Figure 11. S-3B airframe capacity for the conduct of ASW or SSC missions	40
Figure 12. Number of strike/fighter sorties supportable by dedicating all air wing S-3s to tanker missions (mission time over 2 hours)	48

Figure 13. Potential gains in F/A-18 sortie capacity during 1+15, single-cycle operations	53
Figure 14. Potential gains in F/A-18 sortie capacity during 1+45, single-cycle operations	53
Figure 15. SCR limit to airframe capacity	55
Figure 16. NMCS rates for carrier deployments 1/96 to 6/97 and the 1997 Nimitz Surge	59
Figure 17. NMCM rates for carrier deployments 1/96 to 6/97 and the 1997 Nimitz Surge	60
Figure 18. Pilot capacity in the base case.	67
Figure 19. Mission overhead	70
Figure 20. Mission overhead, flight time, and pilot utilization rate	72
Figure 21. Potential gains in F/A-18 pilot capacity	78
Figure 22. Number of F/A-18 pilots required for specified levels of sortie generation.	82
Figure 23. CV/CVW capacity to ready strike/fighters with air-to-ground munitions during an 18-hour flying day.	85
Figure 24. Time between recovery and launch during the 1997 Nimitz Surge.	89
Figure 25. Operating tempo by cycle length during the 1997 Nimitz Surge.	90
Figure 26. Time expended launching an aircraft	94
Figure 27. Time expended recovering an aircraft.	95

List of tables

Table 1.	Potential gains in the capacity of airframes (each squadron)	9
Table 2.	Number of strike/fighter sorties supportable by dedicating all air wing S-3s to tanker missions (mission times under 2 hours)	10
Table 3.	Number of MC aircraft in base case air wing to meet CNO goals	11
Table 4.	Sortie-generation constraints for example calculation	12
Table 5.	Daily capacity of ordnance crews to ready strike/fighters within an 18-hour flying day	12
Table 6.	Daily capacity of ordnance crews to ready strike/fighters within a 24-hour flying day	13
Table 7.	Constraints to carrier and air wing sortie generation	15
Table 8.	USS Nimitz and CVW-9 initial estimate of the population most at risk for fatigue during high-intensity flight operations	19
Table 9.	Augmentees for the 1997 USS Nimitz Surge.	20
Table 10.	Recommended manning levels for augmented billets during high-intensity, 24-hour flight operations	23
Table 11.	Ways to increase firepower capacity over that of the base case	24

Table 12.	Conditions that reduce firepower capacity below that of the base case	25
Table 13.	Air wing composition for the base case	28
Table 14.	CNO goals for MC rates by aircraft type	30
Table 15.	Missions of aircraft	32
Table 16.	Airframe capacity at the 50 percent probability level for each squadron in the base case	37
Table 17.	Airframe flight opportunities during an 18-hour flying day.	41
Table 18.	Number of strike/fighter sorties supportable by dedicating all air wing S-3s to tanker missions (mission time under 2 hours)	47
Table 19.	Potential gains in the capacity of airframes (each squadron).	52
Table 20.	NMCS and NMCM rates (AV3M data) for carrier deployments 1/96 to 6/97 and the 1997 Nimitz Surge.	58
Table 21.	Size of required O-level maintenance augmentation	61
Table 22.	Pilot capacity in the base case.	67
Table 23.	U.S. Navy pilot utilization limits (high-intensity flight operations)	68
Table 24.	Lower bounds for U.S. Air Force pilot utilization rates	69
Table 25.	Inclusion of NSAWC's estimates for mission overhead.	73
Table 26.	Daily capacity of ordnance crews to ready strike/fighters within an 18-hour flying day	84

Table 27. Number of strike/fighters readied using the 1997 Nimitz Surge turnaround rates	87
Table 28. Aircraft fuel capacities	91
Table 29. Average time required by ordnance crews to configure strike/fighters with weapons	94
Table 30. Daily capacity of ordnance crews to ready strike/fighters within a 24-hour flying day	97